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FIRE PROTECTION FOR MUNITIONS IN UNDERGROUND STORAGE FACILITIES

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A wet-pipe fire protection sprinkler system was evaluated for underground ammunition storage. The storage configuration evaluated was four stacks of ammunition boxes; eight boxes wide, nine boxes high and four boxes deep. The individual stacks were separated by 3.5 feet (1m). Selected boxes in each stack contained propellants, pyrotechnics and other highly combustible materials. The sprinkler system used pendent Early Suppression Fast Response (ESFR) K-25, 165°F (74°C) sprinkler heads, manufactured by Tyco, to provide a discharge density of 0.6 gpm/ft2 (24.4 lpm/m2). The system consisted of 20 sprinkler heads. Test fires reflected three potential scenarios: 1) spilled diesel fuel ignition around the base of a box stack, 2) spontaneous ignition of propellant due to loss of stabilizer inside ammunition boxes, and 3) an internal ignition of illumination flares (pyrotechnic composition) from munitions in proximity of the stored ammunition. These tests evaluated the sprinkler system ability to effectively operate, control the fire, and extinguish the fire before adjacent stacks were impacted. Results showed that ESFR K-25 pendant sprinkler heads will operate and inhibit fire spread when exposed to the types of fires conducted. The system will rapidly and thoroughly wet the storage boxes to extinguish and contain fires.</td></tr>
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EXECUTIVE SUMMARY

SCOPE

A modified test facility was used to evaluate a wet-pipe fire protection sprinkler system performance for underground ammunition storage. The test room was approximately 31 feet x 55 feet (9.5m x 17m), with a ceiling height of 14 feet (4m). Four stacks of ammo boxes were placed on the floor inside the facility. The stacks were eight boxes wide, nine boxes high and four boxes deep. The individual stacks were separated by 3.5 feet (1m). Selected boxes in each stack contained propellants, pyrotechnics and other highly combustible materials.

The wet-pipe sprinkler system was designed to use pendent Early Suppression Fast Response (ESFR) K-25 sprinkler heads, manufactured by Tyco, to provide a discharge density of 0.6 gpm/ft^2 (24.4 lpm/m^2). The system consisted of 20 sprinkler heads, and water was supplied from a six-inch centrifugal diesel pump. A draft curtain was installed to minimize the number of fusing sprinkler heads.

Test fires were ignited in a manner to reflect three potential scenarios: 1) spilled diesel fuel ignition around the base of a box stack, 2) spontaneous ignition of propellant due to loss of stabilizer inside the ammo boxes, and 3) an internal ignition of illumination flares (pyrotechnic composition) from munitions in proximity of the stored ammunition. These tests evaluated the sprinkler system ability to effectively operate, control the fire, and extinguish the fire before adjacent stacks were impacted.

BACKGROUND

A joint U.S. Army Corps of Engineers - US Army Operations Support Command (formerly the US Army Industrial Operations Command) team conducted a fire protection engineering evaluation/risk assessment of potential hazards associated with stacked boxes of ammunition in underground storage facilities. The team determined that the risk of an accidental fire or deflagration was high according to the current ammunition storage procedures and standards. Upon further scrutiny, the team made several recommendations for standard underground storage facilities protocols:

1. Install a fire detection system consisting of heat and smoke detectors in the underground ammunition storage facilities to warn of any potential fire threats.

2. Install an automatic sprinkler system for fire suppression to mitigate the fire once detected.

3. Place sand-filled barricades between stacks of ammunition to prevent the propagation of an accidental detonation.

4. Install a portal barricade at the entrance of the underground ammunition storage facilities to reduce external hazards from an accidental explosion.

RESULTS

A diesel fuel spill fire was the threat in scenario 1. In each test, the fire took over 45 seconds to become large enough to activate a sprinkler. The exterior of the ammunition box stack was ignited in the process. A single sprinkler activated and controlled the fire quickly. No acceptor charges were ignited during the tests and adjacent stacks were not affected.

The scenario 2 threat was a spontaneous combustion of propellant due to the loss of stabilizer from the bottom middle ammunition box on the outside of stack 2. These fires burned intensely immediately after ignition. In each evaluation, 10 or more sprinklers opened within 15 seconds of ignition. The sprinkler system controlled and extinguished each fire. There was no resulting damage to the adjacent ammunition stacks and little damage to boxes near the propellant donor charge. However, the temperature in the acceptor charge boxes did increase in the spontaneous combustion scenario. The plastic wrap covering the acceptor charge propellant showed signs of heat damage in the ammo box closest to the donor charge. No acceptor charges ignited.

For scenario 3, two illumination canisters from 4.2 inch (107 mm) mortar rounds were used. They contained 6.6 pounds (3 kg) of illumination composition. They were located in the top middle ammunition box on the outside of stack 2. The flares burned energetically with flames emitting from the box and sparks raining on stack 3. A maximum of two sprinklers activated within 16 seconds in each test and controlled the fire until the illumination flare canisters burned out (90-120 seconds after ignition). After that the fire was extinguished quickly. There was no resulting damage to the adjacent ammunition stacks and little damage to boxes near the illumination canisters.

An additional test was conducted after all of the scenario tests were completed at the request of the technical advisor Mr. Bob Loyd. This test evaluated the sprinkler system's effect on a fire originating at the bottom of an ammo box stack. The stack was five boxes wide, five boxes high and four boxes deep. Propellant and illumination composition (2 pounds

[0.9 kg] of JA-2 propellant, 5 pounds [2.3 kg] of LKL propellant, 13 pounds [5.9 kg] of M1 propellant, and 6.6 pounds (3 kg) of illumination composition [2 canisters]) were placed in the bottom middle ammo box to produce a condition exceeding worst case. The result was an intense fire that activated 15 sprinkler heads. The sprinkler system controlled the fire and damage was limited to a few ammo boxes in the vicinity of the donor box.

The draft curtain contained the combustion gases to the area of fire origin. The charts on Row 5 for each test in Appendix I clearly show that temperatures outside the draft curtain containment (non-fire side) were controlled.

CONCLUSIONS

1. The ESFR K-25, 165°F (74°C) pendant sprinkler heads will operate and inhibit fire spread when exposed to the types of fires conducted in this test series. The system will rapidly and thoroughly wet the storage boxes to extinguish and contain fires.

2. The sprinkler system evaluated will contain a diesel fuel spill fire and minimize the resulting damage to ammunition storage containers and the facility.

3. A spontaneous combustion fire of 17 pounds of propellant can be limited to the ammunition box of origin and adjacent boxes.

4. The sprinkler system will not extinguish the illumination canisters, however, it will contain the fire, protect surrounding ammunition boxes and prevent fire spread to adjacent ammunition stacks.

5. A draft curtain will prevent excess sprinklers from opening. No sprinklers outside the draft curtain containment opened during the tests.

6. The optical flame detectors used in the tests could be valuable for detecting fires and initiating an alarm system in munitions storage locations. These detectors responded in less than five seconds to each fire when the field of view of the detector was unobstructed.

RECOMMENDATIONS

1. Recommend the K-25 sprinkler system, as tested in these evaluations, be installed for protection of stacked box ammunition

storage areas. In each test the fire was controlled, extinguished and did not spread to adjacent stacks.

2. In this test series, it was determined that the water application rate tested was more than adequate to control the fires and to prevent the fire spread to adjacent stacks. To optimize the suppression system however, additional tests can determine the minimum required application rate for controlling these fire scenarios. Future evaluations should consider other evaluations of the K-25 and K-17 sprinkler heads and the use of water mist technology. Suggest future evaluations be conducted to include the following:

   a. Additional scenarios (only three were conducted in these evaluations)

   b. Vary locations of donor/acceptor charges (i.e. center of stacks, closer together, etc.)

   c. Vary pressures/flow rates. Lower flow rates/pressures may save substantial amounts of water, pipe size and pump capacity.

   d. Evaluation of upright K-25 sprinkler heads vs. pendant K-25 sprinkler heads. Future tests might also include support beams or other equipment that might obstruct the sprinkler heads (as found in real world storage compartments).

3. In the test series using flowing fuel on the floor, it became apparent that the use of pallets would allow the burning fuel to flow under the stacks making it difficult to extinguish the fires. However, with the boxes sitting directly on the floor, the fuel was contained to the edge of the boxes permitting easy containment by the overhead sprinklers. Although it is easier to move the stacks on pallets, recommend for fire control that the boxes be placed directly on the floors. Recommend this situation be examined in future evaluations.

4. This evaluation series did not examine disposal of the copious amounts of water generated on the floor surrounding the test stacks. In real situations the slope of the floor and a collection of the discharged water will be important considerations. Recommend this situation be examined in future evaluations.

5. Recommend the use of draft curtains such as the 54" (137 cm) steel curtain used in the evaluations. The curtain prevented excess sprinklers from opening as no sprinklers outside of the draft curtain area opened during the tests.

ADDITIONAL COMMENTS AND SUGGESTIONS

In addition to the recommendations above, the following points are in this report as observations, comments or suggestions.

1. Copious amounts of smoke generated in each test necessitated the use of IR cameras to determine what was occurring in the fire area both during and after a fire scenario. Where resources permit, underground storage areas should be equipped with CCTV and IR cameras to facilitate actual observation of a fire scenario. In addition, a smoke removal system should be considered in such situations.

2. In actual situations, consider feeding the water supply system from two remote locations (opposite ends) and other means to reduce the vulnerability of the system to accidents. In addition, consider the use of (ARMCO) barricades and smoke doors/separations within the storage area.

3. The storage of ammunition on pallets loaded in MILVANs or CONEX containers is a common practice often used for combat units deploying to the field. These containers could hold non-compatible ammunition items such as white phosphorus projectiles and mortar rounds. This study does not address the issue of the storage of ammunition in MILVANs or CONEXs, however, the threat should be evaluated in future studies. Fire detection and suppression inside the shipping containers that permit quick and easy connections and disconnections, such as from a manifold system, will be needed. Some types of ammunition will also require special arrangements (e.g. The only way to stop burning white phosphorus is to deprive it of air such as by covering it with water).

4. Fire modeling, in future evaluations of potential fires in underground munitions storage areas, could produce a better understanding of the fire dynamics of burning propellants and pyrotechnics.

   a. "Modeling Missile Propellant Fires in Shipboard Compartment", by Derek A. White, Craig L. Beyler, Fredrick W. Williams, and Patricia A. Tatem, published in the Fire Safety Journal discussed this issue. A modified version of FAST, an existing computer fire model, takes into account the fire phenomena specific to missile propellant combustion. The modified computer program and the developed missile propellant burning rate algorithm corrected predicted the results of full-scale burn tests. (Fire Journal, #34 (2000) 321-341).

b. Recent DOD Explosives Safety Seminars that touch on this area:

   – Potential Fire and Explosion Hazards of a Range of Loose Pyrotechnic Compositions by Roy Merrifield.

   – Non-Thermal Effects From Hazard Division 1.3 Events Inside Structures by Mile Swisdak, Jr.

   – Propagation of Firebrands From Burning Ammunition Stacks by Warren W. Hillstrom.

   – Prediction Techniques for Overpressure and Thermal Risk From C/D 1.3 Materials During Processing.

   – Hazard Division 1.3 Passive Structural Systems Design Guide by Joseph Serna.

   – HD 1.3 Quantity-Distance Shorter But Still Safe by Dr. B. Lawton.

   – Scaling Studies of Thermal Radiation Flux From Burning Propellants by J. Edmund Hay.

c. The Center for the Simulation of Accidental Fires & Explosives (C-SAFE) is an organization associated with the University of Utah. The goal of C-Safe is to develop the technical capability to simulate accidental fires and explosions involving hydrocarbons, structures, containers and high-energy materials. One of the possible scenarios to simulate is a fire at an explosives manufacturing plant. Recommend contacting this organization as a potential source of information.

5. The NATO Underground Ammunition Storage Subcommittee, the country of Singapore, DOD Explosives Safety Board, and the individual services are very interested in this work and how they can benefit from the information gathered. Recommend submitting a paper on this topic to publications such as: Fire Journal, Fire Technology, Fire Protection Engineering, Safety Professional and similar commercial sector/military publications .

6. Recommend follow-on, larger scale test evaluations, incorporating recommendations and comments in this report, be conducted in the Hanger Facility at the DOD Fire Lab located at Tyndall AFB, FL. This facility has more area and a significantly higher ceiling. In addition, craftsmen and engineers are readily available to

retrofit the facility for these additional tests and to provide the analysis necessary for additional documentation and reports.

DEFINITIONS

Acceptor Charge – Energetic material (in this test series, 0.25 pounds [113g] of propellant) that can ignite due to the accidental deflagration of nearby energetic material.

Ammunition and Explosives (A&E) - includes ammunition, propellants, high explosives, warheads, mortar rounds, tank gun rounds, small arms, pyrotechnics and related type items. The A&E used in the tests were not intended to detonate, however, deflagration and flaring were possible.

Donor Charge - Energetic material (17 pounds [7.7kg] of propellant in test scenarios 1 and 2 or two illumination canisters [6.6 pounds {3kg}] in scenario 3) that ignites leading to a fire with potential to ignite nearby energetic material.

ESFR – Early Suppression Fast Response

GPM – Gallons per Minute

LPM – Liters per minute

SECTION I - INTRODUCTION

SCOPE

This project evaluated the effect of a wet-pipe sprinkler system to protect known fire hazards with ammunition and explosives stored in wooden boxes located in underground storage facilities. (The work is also applicable to earth covered magazines.) During normal operations in these underground facilities, there is an influx of vehicles and material handling equipment entering and leaving to store, reposition or remove boxes of ammunition. Vehicle traffic poses a fire threat to personnel working around the stacked ammunition. In cases where repositioning or relocation does not occur, there is a possibility for spontaneous combustion from propellants due to the lost of stabilizer, and ammunition/explosives stored over long periods of time that could cause personnel injury or death.

An investigation of these underground storage facilities produced three likely scenarios that could cause fires. These include: 1) accidental fuel spills under stored boxes of ammunition, 2) spontaneous combustion from inside a box of ammunition/propellant, or 3) heat generated from a flare burning inside wooden ammunition boxes.

Specifically, this work encompassed evaluating the effectiveness of an installed wet-pipe sprinkler system with pendent Early Suppression Fast Response (ESFR) K-25 low pressure, high flow rate heads to contain a fire in stacked boxes of ammunition. Success was measured by the systems effectiveness in preventing propagation to other stored ammunition or limiting the damage done to adjacent stacks. Success was also measured by the draft curtain's effectiveness to reduce the number of fusing sprinklers and therefore maintain system pressure.

BACKGROUND

A joint US Army Corps of Engineers (USACE)-US Army Operations Support Command (formerly the US Army Industrial Operations Command) team conducted a fire protection engineering evaluation risk assessment of potential hazards associated with stacked boxes of ammunition in underground storage facilities. The team determined that the risk of an accidental fire or deflagration was high according to the current ammunition storage procedures and standards. Upon further scrutiny, the team made several recommendations for standard underground storage facilities protocols:

1. Install a fire detection system consisting of heat and smoke detectors in the underground ammunition storage facilities to warn of any potential fire threats.

2. Install an automatic sprinkler system for fire suppression to mitigate the fire once it is detected.

3. Place sand-filled barricades between stacks of ammunition to prevent the propagation of an accidental detonation.

4. Install a portal barricade at the entrance of the underground ammunition storage facilities to reduce external hazards from an accidental explosion.

OBJECTIVE

The objective of this test program was to determine if a relatively low-cost wet-pipe fire suppression system (fusion link sprinkler) can prevent the spread of a fire that may occur with clusters of ammunition and explosives filled wooden boxes to safeguard underground ammunition storage facilities or earth covered igloos. This test program specifically targeted the adequacy of the water application density of .60 gpm/ft^2 (24.4 lpm/m^2) , and whether a draft curtain prevented unnecessary discharges of sprinkler heads in areas away from the fire threat.

The intent of the sprinkler protection was to prevent the growth and propagation of a fire/deflagration that initially involves munitions in storage containers. The sprinkler system was not intended to protect against explosive blasts or detonations.

The sprinkler system used in these evaluations was an early suppression fast response (ESFR) type.

> *NOTE: While standard and large-drop sprinklers offer fire "control" of warehouse fires, ESFR sprinklers are meant to perform in suppression mode, that is, to actually extinguish the fire. By contrast, standard sprinklers confine a fire by pre-wetting combustibles surrounding the area of the fire and by cooling hot gases at the ceiling; extinguishment rarely occurs without fire department intervention. ESFR sprinklers are highly sensitive to heat – much more so than standard sprinklers – so they activate at an earlier stage in fire development. Moreover, they discharge a large volume of water at high momentum directly into and through the fire plume.*
>
> *A single ESFR sprinkler will discharge up to 125 gallons per minute of water, or about five times as much as a standard sprinkler. The*

ESFR's deflector produces a broad spray pattern to control fire between sprinklers, while the orifice maintains a high-force downward to penetrate and suppress fire directly below.[1]

Current ESFR requirements allow for protection of storage up to 35 feet (10.7 m) and building heights to 40 feet (12.2 m).

Five (5) specific areas were to be evaluated from this test series:

1. Successful initiation/operation of installed fire protection sprinkler system.

2. Suppression and extinguishment of fires and prevention of the fire from spreading to other stacks of ammunition boxes stored in proximity.

3. Suppression of a fire generated from within a stack of munitions as demonstrated by a simulated internal spontaneous combustion fire such as propellant with low stabilizer content.

4. Evaluation of a draft curtain to contain the initial spread of hot gases to maximize suppression system response time and maximize suppression system water pressure by preventing the opening of excess sprinkler heads.

5. Establish a baseline storage configuration with respect to stack height, stack size, stack separation, quantity of ordinary combustible materials and proposed storage density of explosive material.

SECTION II - TEST PROCEDURES AND SETUP

TEST SETUP

The preparation process for this series of tests involved retrofitting the NATO facility (Figure 1) at Test Range II Tyndall AFB, FL to the likeness of an underground munitions storage facility. The room, shown in Figure 2, where tests were conducted is 31 feet x 55 feet (9.5m x 17m), with a ceiling height of 14 feet (4m). The facility floor was lined with 3/8 in (0.95 cm) steel to contain the test effluent. A sprinkler system was installed along with a 2000 gpm (7570 lpm) centrifugal water pump specifically leased for this purpose. The facility was instrumented with four video cameras, one IR video camera, thermocouples, two Detector Electronics Unitized UV/IR optical flame detectors (see Figure 3), a water flow meter and a data acquisition system. Exhaust fans were remotely controlled with the data acquisition system.

Figure 1: NATO Facility

Figure 2: NATO Facility Test Room

A steel lip of approximately 24 inches (60.96 cm) high was constructed around the interior perimeter of the facility to contain the water and debris from each test. This lip was constructed of 0.25 inch (.635 cm) steel. This containment could hold up to 27,000 gallons (102,000 liters) of water per test. After each test, the water was filtered to separate all propellant and pyrotechnic material before disposal in accordance with base environmental procedures. The columns in the test area were wrapped (to limit spalling) with 0.25 inch (0.64 cm) steel bands to a height of 4ft (1.22 m). The port area that covered the manhole for the basement was replaced with a flush, watertight steel hatch that was designed and manufactured for this purpose.

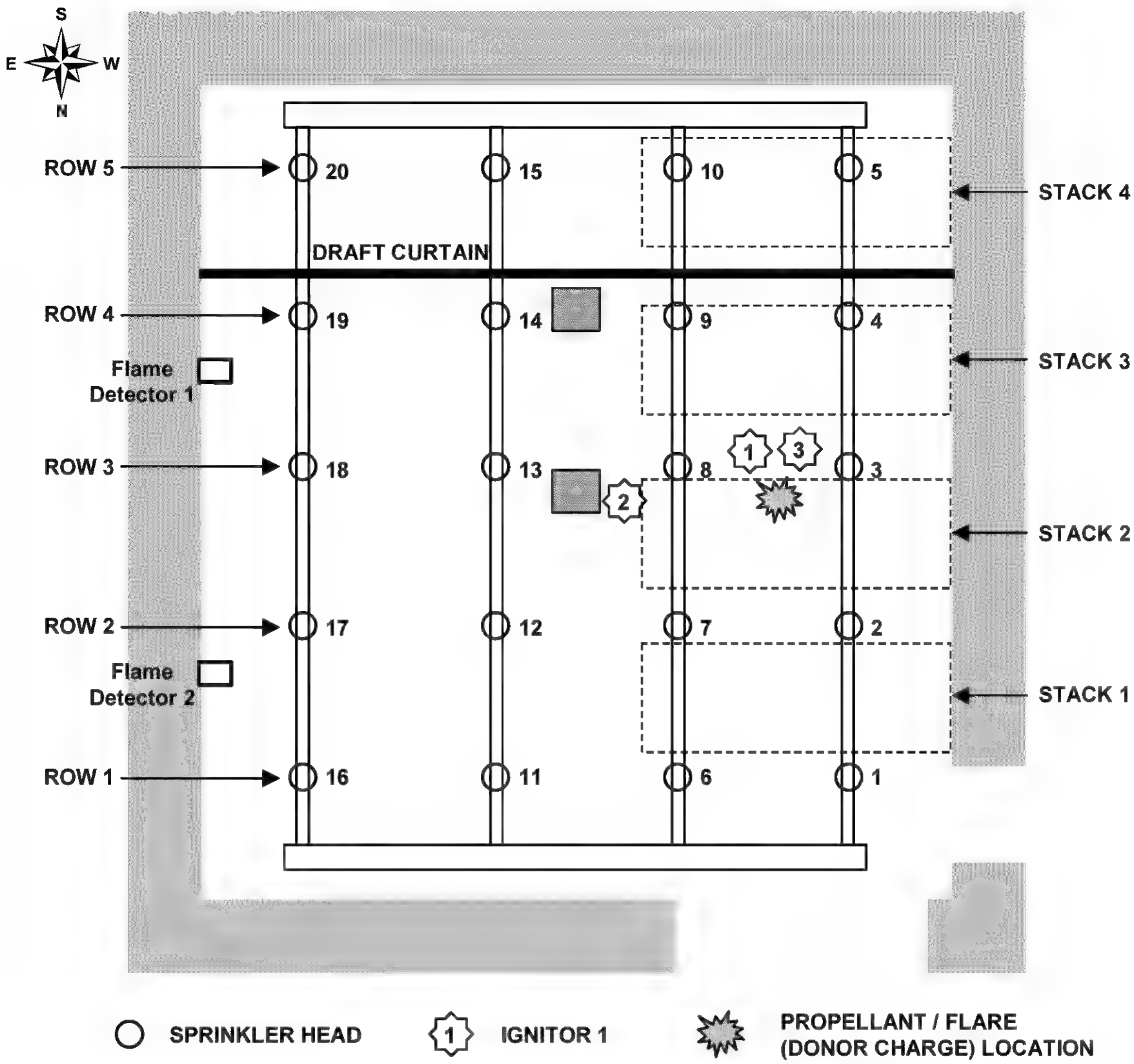


Figure 3: Facility Arrangement (Top View)

The type of sprinkler heads for this series of tests were selected by the US Army Operations Support Command (formerly the US Army Industrial Command) because of their low pressure (20 psi [137.8 kPa]) requirements for high output (100 gpm [379 lpm]). The Pulsar ESFR-25 (Figure 4) is a pendent sprinkler manufactured by Tyco with a nominal K-factor of 25.2 gpm/psi$^{1/2}$ (36.3 lpm/kPa$^{1/2}$). The sprinkler heads used were rated at 165°F (74°C). They were installed in the facility on 8 feet X 11 feet (2.4 m x 3.4 m) spacing. The sprinklers were instrumented and opening times during the test were recorded on the data acquisition system. Figure 5 shows a discharge test with four sprinklers open.

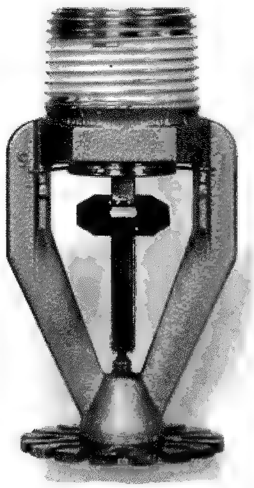


Figure 4: Pulsar ESFR-25 Sprinkler Head

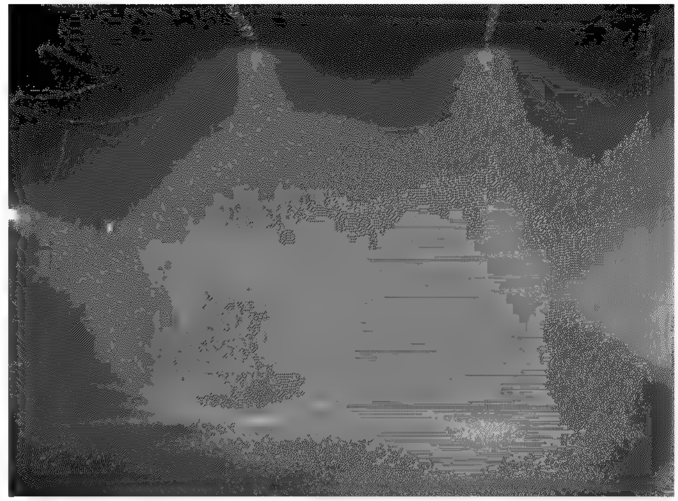


Figure 5: Four Discharging Sprinklers

The sprinkler system was designed by the K-Factor Company to deliver 1.0 gpm/ft^2 (40.7 lpm/m^2) using a pump that supplies a minimum flow rate of 1421 gpm (5380 lpm)at 65 psi (448 kPa) and maintains the recommended pressure (20 psi [138 kPa] per sprinkler) for 12 opened heads that have a K-factor of 25. (Suppression of a full-scale fire typically occurs with the activation of a maximum of 12 sprinklers.) Hydraulic design information is included in Appendix B. These parameters were adjusted to deliver the proposed cover density of 0.6 gpm/ft^2 (24.4 lpm/m^2), with 54.5 gpm (206.3 lpm) at 11 psi (75.8 kPa), to validate the system's effectiveness for suppression. The proposed density was chosen due to water supply limitations in remote locations for these facilities. The maximum water pressure in the system was limited to 40 psi (276 kPa) with a Cla-Val pressure-sustaining valve.

The sprinkler system consisted of a six-inch manifold with three inch feeder lines. It was suspended from the ceiling on Clevis Rings anchored by all-threads that were embedded 0.25 inches (0.64 cm) into the concrete ceiling. The sprinkler system suspension system was re-enforced with four steel columns at critical locations. There were 20 (twenty) sprinkler heads installed, five rows with four sprinkler heads per row.

The draft curtain was constructed from sheets of 18 gauge-galvanized steel that extended across the width of the test room as one continuous barrier. The curtain was attached flush to the test room ceiling, walls and around the pipes that were in place for the sprinkler system. It initially extended approximately 30 inches (0.76m) from the ceiling and was extended by an additional 24 inches (0.61m) during latter stages of the test series to improve its effectiveness (see Conclusions #5 and

Recommendations #5). All openings around the curtain were filled with polyurethane foam to prevent leakage.

Data from the temperature sensors, flow meter and sprinkler heads were recorded at 1-10 Hz, depending on the test scenario, on a Pentium computer using National Instruments PXI and SCXI hardware and LabView Windows-based software. Temperatures were measured with type K thermocouples at each sprinkler head and near the ignition point. Sprinkler head opening times were measured with a low-current signal connected to each head. An Omega FP-6000 flow sensor was used to record the total water flow rate through the sprinkler system.

A typical ammunition box used in this test series is shown in Figure 6 and was acquired from Army sources. The boxes were constructed out of wood with dimensions 12 inches (30.5 cm) wide by 8.5 inches (21.6 cm) high by 36.5 inches (92.7 cm) long. Each stack of ammo boxes contained 288 boxes that were stacked eight boxes wide by nine boxes high by four boxes deep. There were four stacks of ammo boxes in the facility (see Figure 3). The ammo boxes were not placed on pallets but were stacked on the floor of the facility as they are in underground storage facilities.

Figure 6: Ammunition Box

TEST PROCEDURES

Nine evaluations were planned in this series, three tests in each of the planned scenarios. Two additional tests were also conducted, a Scenario 1 test and an unplanned scenario.

SCENARIO 1

Tests 1-3 and 10 simulated an external fire initiated by an accidental diesel fuel spill from a forklift or vehicle accident. Five gallons of diesel fuel were placed in a containment area near the donor charge box (17

pounds [7.7kg] of M-1 propellant) and around the donor stack (Stack #2). The fuel was ignited using a remote controlled electric match inside of two plastic bags filled with 0.25 pound (113g) [0.5 pound {227g} in Test 2] mixture of smokeless powder, JA-2 and M-1 propellant. In each test, 0.25 pounds (113g) of propellant material was placed in open metal pans inside pre-selected closed wooden boxes within the stacks in an unconfined manner. (**Note that unconfined in this test series is defined as not compressed or not held tightly to reduce the possibility of a detonation of the material**). The metal containers had a plastic wrapping over them to repel excess moisture or water that may be present during the test. Figure 7 - Figure 9 show the placement of the donor charge and the 0.25 pound (113g) containers of loose propellant for all stacks. In Tests 2 and 10 a modification was implemented consisting of igniting the donor charge after the sprinkler system had brought the initial fire under control.

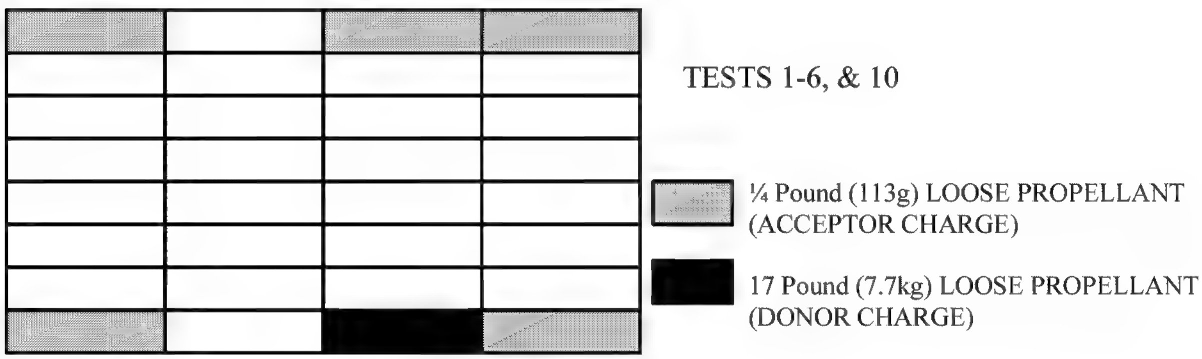


Figure 7: Tests 1-6 and 10, Stack 2 Side View - Facing Stack 3

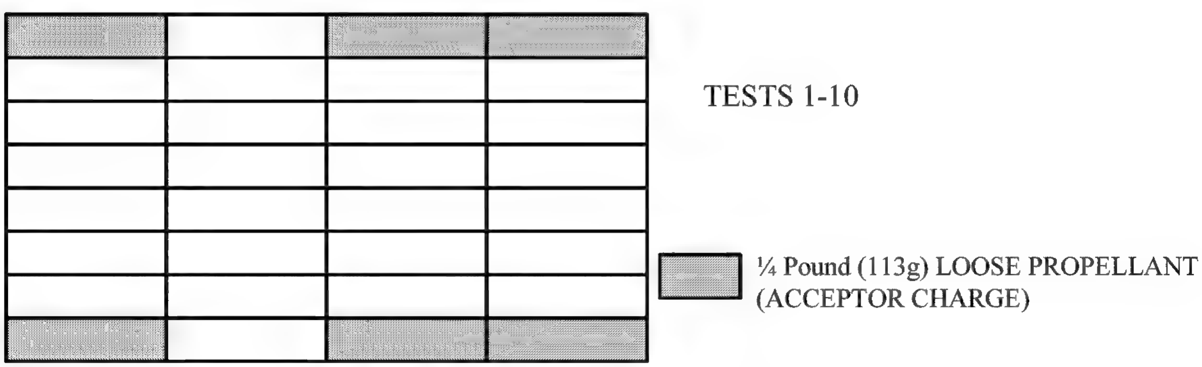


Figure 8: Tests 1-10, Stacks 1-4 Side View

(Excluding the Stack 2 side shown above. Also no acceptor charges were placed on the outside of Stacks 1 and 4)

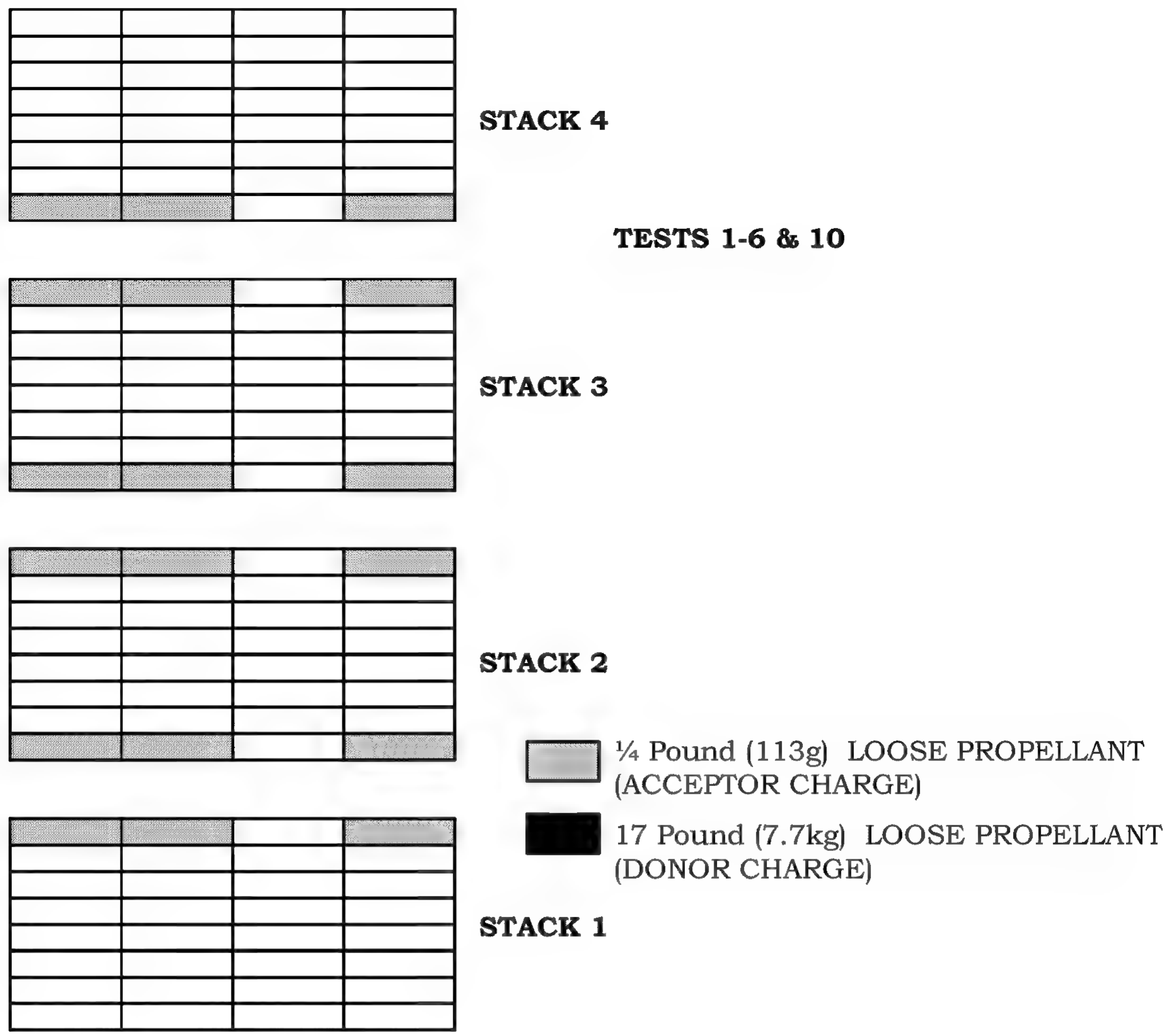


Figure 9: Tests 1-6 and 10, Top View

<u>SCENARIO 2</u>

Tests 4-6 simulated an internal fire caused by spontaneous combustion of munitions/ammunition in the center stack. The boxes adjacent to the ignition source box also contained propellant. The donor charge (17 pounds (7.72 kg) of M1 propellant) was electrically ignited with a remote controlled match inside of a plastic bag filled with a 0.25 pound (113g) mixture of smokeless powder, JA-2 and M-1 propellant. In each test, 0.25 pounds (113g) of propellant material was placed in open metal pans inside pre-selected, closed wooden boxes within the stacks in an unconfined manner. Figure 7- Figure 9 show the placement of the donor charge and 0.25 pound (113g) increments of loose propellant for the donor stack and the acceptor stacks.

SCENARIO 3

Tests 7-9 simulated the spontaneous ignition of pyrotechnic material in one of the upper level boxes in the center stack. The pyrotechnic material was illuminating canister assemblies (illumination composition) from M335A2 4.2 inch (10.6 cm) mortar rounds weighing 3.3 pounds (1.5 kg) each. Two canisters were ignited by a remote controlled electric match. In each test, small amounts of propellant material (acceptor charges) were placed in open metal pans inside closed wooden boxes within the stacks in an unconfined manner. Figure 8, Figure 10 and Figure 11 show the placement of the donor charge (illumination canisters) and acceptor charges (0.25 pound [113g] containers of loose propellant).

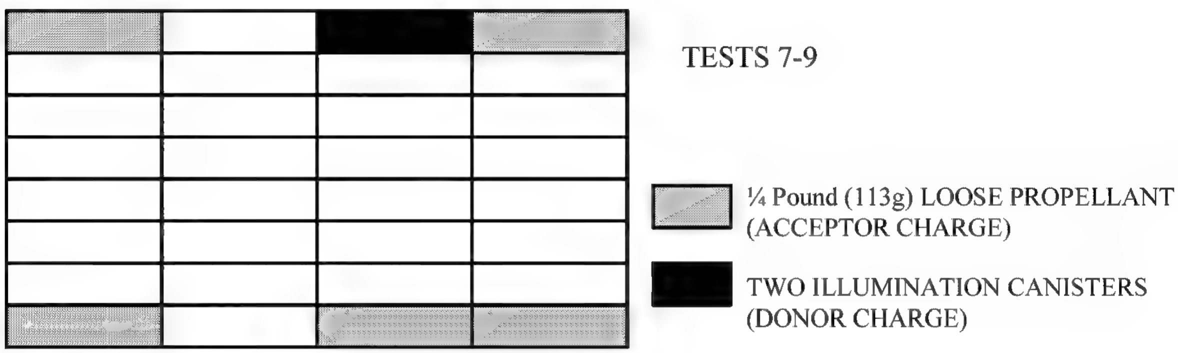


Figure 10: Tests 7-9, Stack 2 Side View - Facing Stack 3

A scenario not originally described in the test plan, was also prepared and performed at the request of the technical advisor Mr. Bob Loyd. Boxes were stacked five high X five wide X four deep. Propellant and illumination composition were placed in the bottom middle ammo box (2 pounds [0.9 kg] of JA-2 propellant, 5 pounds [2.3 kg] of LKL propellant, 13 pounds [5.9 kg] of M1 propellant, and 6.6 pounds (3 kg) of illumination composition. This test evaluated the sprinkler system effectiveness on a fire originating at the bottom of an ammunition box stack.

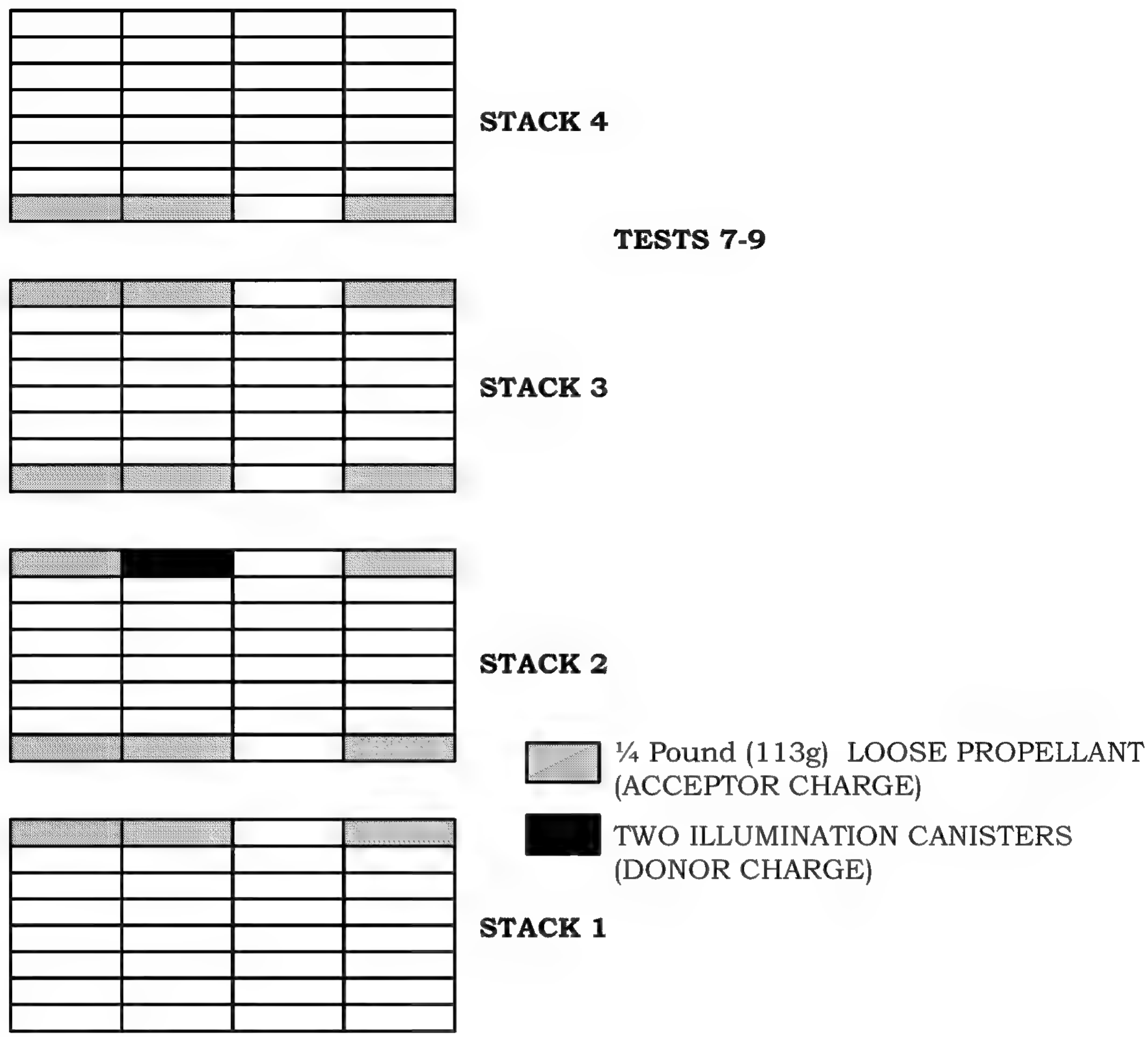


Figure 11: Tests 7-9, Top View

SECTION III - RESULTS

All tests were set up and executed as described in Section II. This section describes the events and results of all 11 tests. Appendix I contains charts of ceiling temperature data from each of the tests. For each test, there is a single chart with all of the ceiling temperatures and there are five charts with the ceiling temperatures for each row as described in Figure 3. Also, one page of selected contour plots of ceiling temperatures are included in the appendix for each test.

TEST 1

This test was conducted on 2 February 2001 in the Scenario 1 method of a fire started near an ammunition stack after an accidental diesel fuel spill. There were four stacks of ammo boxes in the facility; eight boxes wide by nine boxes high by four boxes deep. Figure 12 and Figure 13 below show the facility before ignition of the evaluation fires. Five gallons (18.9L) of diesel fuel were spilled around stack 2. For repetition, three ignition sources (consisting of an electric match embedded within 0.5 pound [227g] of propellant) were installed to initiate diesel combustion. The sources were located on the side and front corner of stack 2 as shown in Figure 3. An electric match was used to initiate the ignition source. The flame from the primary ignition source ignited the #3 ignition source adjacent to it. Both bags combined produced enough heat to set off sprinkler #3 just as the fuel ignited and before the ammo boxes ignited. The sprinkler flowed approximately 200 gpm (757 lpm) and completely extinguished the fire nineteen seconds after ignition. The sprinkler system pressure was maintained at 40 psi (276 kPa) maximum with a Cla-Val pressure-sustaining valve in this and all tests. Flame detector 1 (see Figure 3) alarmed one second after ignition and detector 2 responded six seconds after ignition. The donor and acceptor charges had no damage and there was only minor damage to the exterior of the ammo boxes. The decision was made to reduce the quantity of propellant in the ignition sources to 0.25 pounds (113g) for future tests.

Figure 12: Test Facility Stacks 1, 2, & 3

Figure 13: Test Facility Stacks 2 (right) & 3

TEST 2

This test was conducted on 6 February 2001 as described in Scenario 1 with the modification of also manually igniting the donor charge propellant after a sprinkler fused from the fuel fire. Five gallons (18.9L) of diesel fuel were spilled around stack 2. Two ignition sources were located at the front corner of the stack as shown in Figure 16. The third source was placed inside of the donor charge. The primary match was ignited first. It was followed by the secondary match 19 seconds later. This produced a diesel fuel fire that propagated to the ammo boxes. Figure 14 shows the fire before the sprinkler fused. Flame detector 1 alarmed three seconds after the primary match and detector 2 responded four seconds after it. The fire resulted in a single sprinkler opening; sprinkler #8, 72 seconds after the second ignition source was initiated (Figure 15). This sprinkler flowed 200 gpm (757 lpm) and extinguished the fire. Just before the fuel and ammo box fire was extinguished and 107 seconds into the test, the donor charge (17 pounds [7.7 kg] of propellant) was remotely ignited with an electric match by the test director. The fire from the propellant was very intense and in a matter of seconds caused five more sprinklers to open (numbers 2, 3, 4, 7 and 9). This increased the water flow rate to 700 gpm (2650 lpm) and the flow density on the ammunition boxes was 1.3 gpm/ft.^{2} (52.9 lpm/m^2). The water contained the fireball and kept the fire from spreading. The external fire was extinguished 15 seconds after donor charge ignition and the donor charge was quenched one minute after ignition. Adjacent ammo stacks were protected. Figure 16 shows the igniter locations and the sprinkler opening times.

Figure 14: Test 2 Fire, 9 Seconds Before Sprinkler Activation

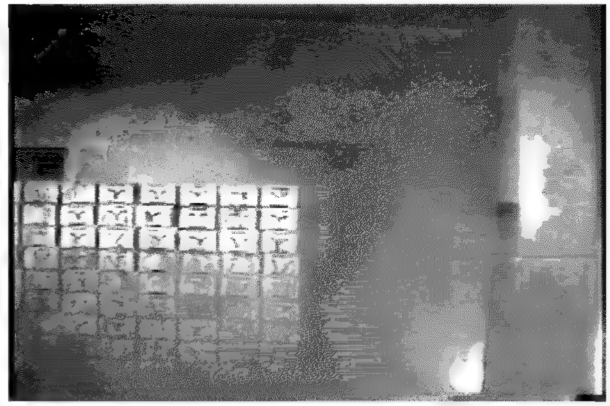


Figure 15: Test 2 Fire, 2 Seconds After Sprinkler Activation

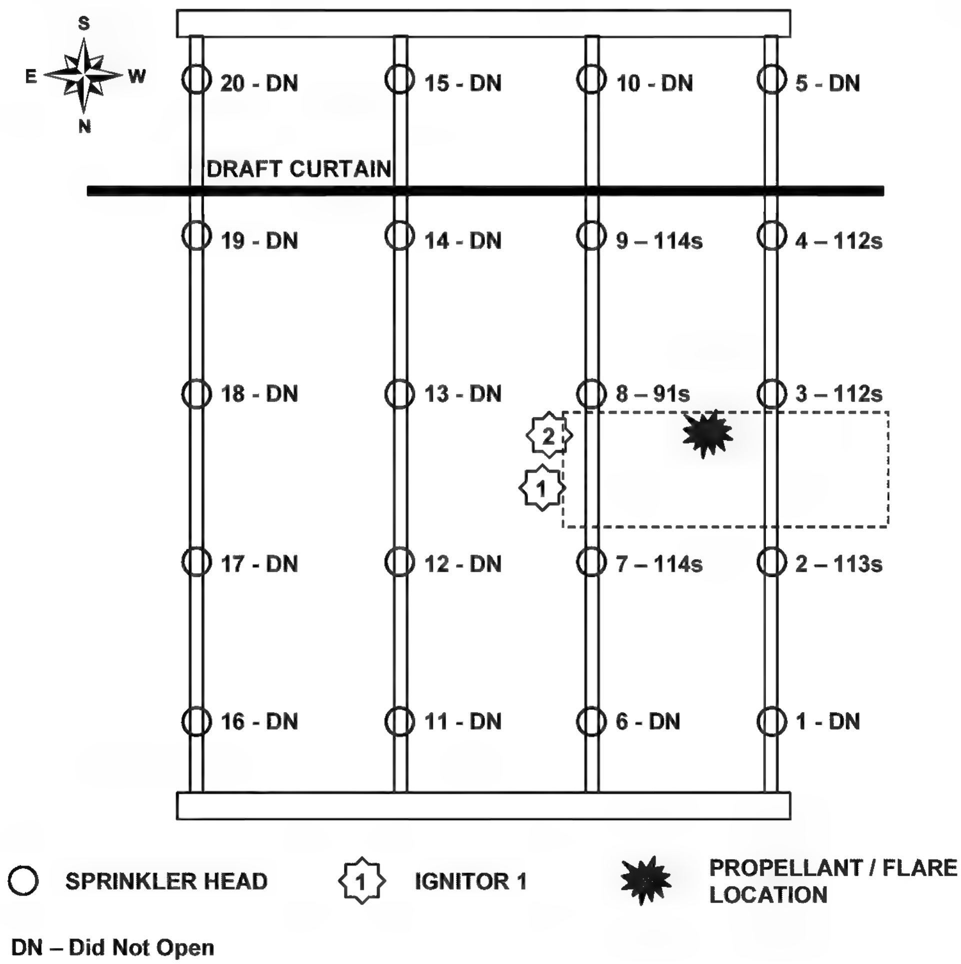


Figure 16: Test 2 Sprinkler Head Time to Open

TEST 3

This test was conducted on 19 March 2001 as described in Scenario 1. Five gallons of diesel fuel were spilled around stack 2. Two ignition sources were located at the side and front of the stack as shown in Figure 3. The igniter at the side, number 1, was ignited first. The fire spread to two of the lower ammo boxes and the temperature outside the donor charge box increased to 900°F (482°C) within 20 seconds, however, this fire began to die down quickly and showed no signs of propagating. Igniter 2, at the front of the stack, was fired 64 seconds later. There was more diesel fuel pooled on the floor at this location and this fire grew rapidly and propagated to the ammo boxes. Flame detector 1 recorded the initial flame two seconds after ignition. Detector 2 did not see the initial flame, however, it responded five seconds after the second ignition source was initiated. The fire resulted in a single sprinkler opening, sprinkler #8, 48 seconds after the second ignition source was initiated (113 seconds after the first ignition source). This sprinkler flow averaged 350 gpm (1325 lpm) and contained the fireball within 5 seconds and kept the fire from spreading. The fire continued to flicker for 80 seconds after the head opened, and then it went out. Adjacent ammo stacks were protected.

Figure 18 shows selected contour plots of the ceiling temperatures for Test 3. The plots show the temperature profile at two-second intervals. Each intersection in the plots represents one of the 20 sprinkler locations as shown in Figure 3. These plots have been animated for each test with 1-10 plots per second and an average of 250 plots per animation. The animations are available from the report authors. Figure 17 shows the temperature scale for the contour plots in Fahrenheit and Celsius degrees. Appendix 1 shows one page of contour plots for each test.

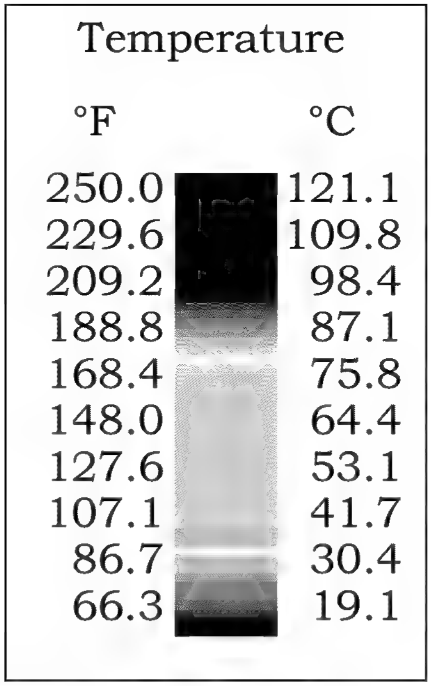


Figure 17: Fahrenheit to Celsius Conversion

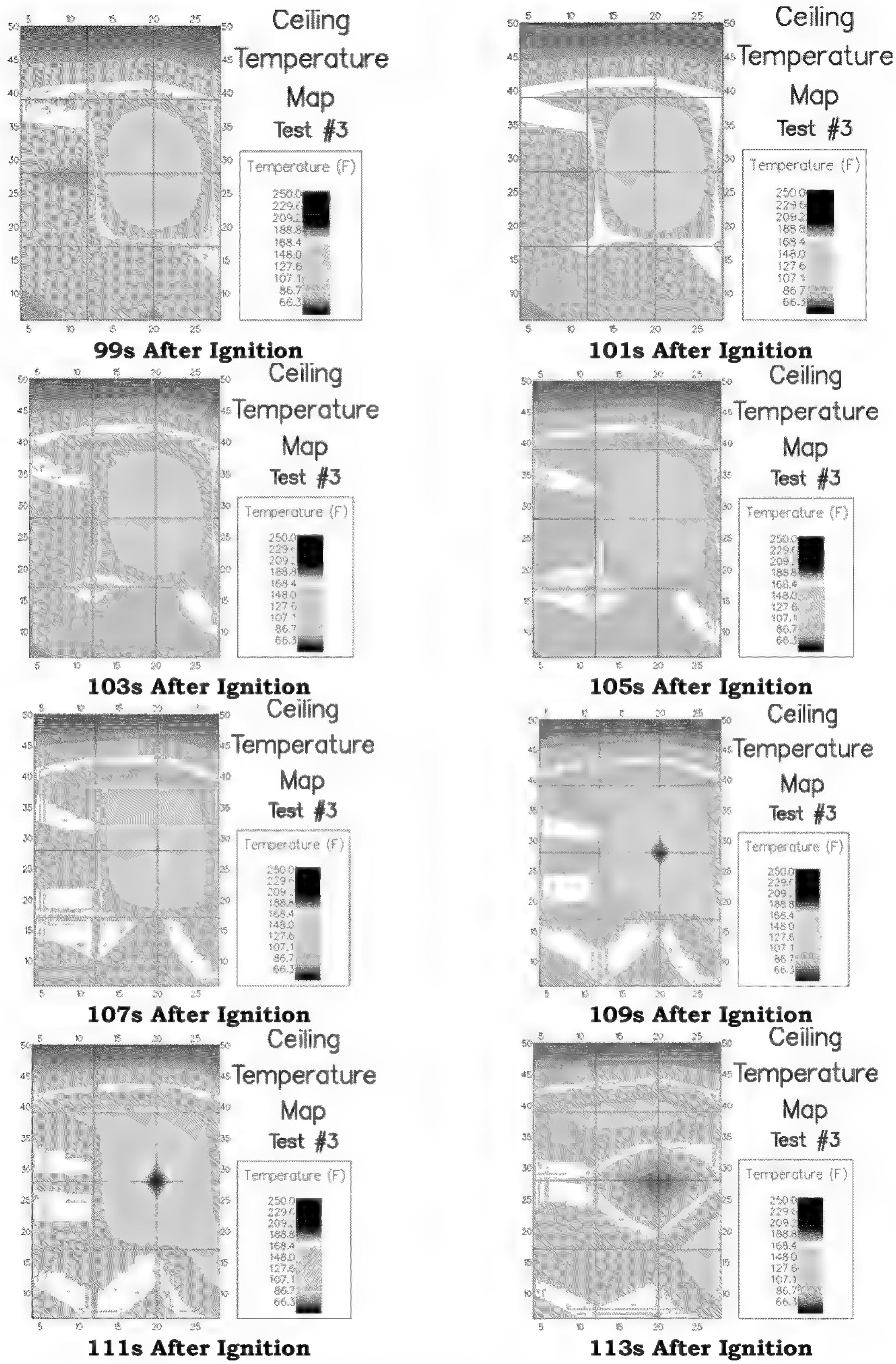


Figure 18: Test 3 Ceiling Temperatures @ 2 Second Intervals

TEST 4

This test was conducted on 9 February 2001 as described in Scenario 2. The test simulated spontaneous combustion of the donor charge (17 pounds [7.7kg]of unconfined propellant) inside an ammo box. To create an even more intense fire, approximately three gallons (11.4L) of diesel were spilled onto ammo boxes adjacent to the donor charge. An electric match was used to ignite the donor charge. Upon ignition, the propellant produced large jets of fire through the ammo box seams. Flames impacted and penetrated the adjacent ammo stack 3 for approximately eight seconds after ignition as shown in Figure 19. Flame detector 1 recorded the flame two seconds after ignition and detector 2 responded six seconds after ignition. Ten sprinklers above and around the donor stack opened within 14 seconds after ignition. Figure 20 shows the controlled fire after sprinkler activation. The infrared video camera in the facility allowed viewing through the water spray and the fire appeared to be extinguished after one minute. However, 190 seconds after ignition, while the sprinklers were still flowing, a momentary flash emitted from the donor charge ammo box. After this event, no other signs of flame were visible. The sprinklers flowed water for five minutes during the test at 70 gpm (265 lpm) per head and a flow density of 0.88 gpm/ft.^{2} (35.8 lpm/m^2) on the ammunition stack. The fire was contained and did not spread to adjacent ammo stacks, as stated above, although stack 3 had flame impingement during the initial stage of the fire. All fusing sprinklers were within the draft curtain area. Figure 21 shows the propellant location and the sprinkler opening times.

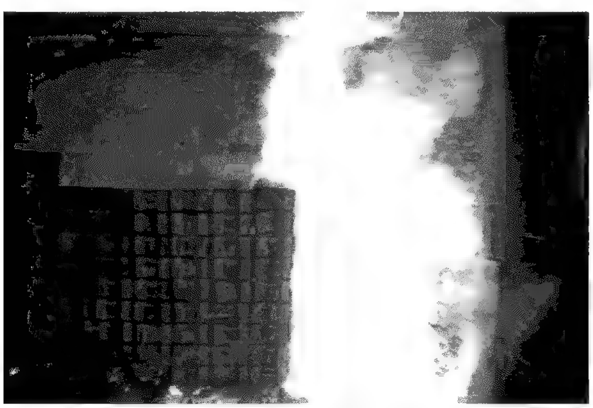


Figure 19: Test 4 Fire, 4 Seconds After Ignition

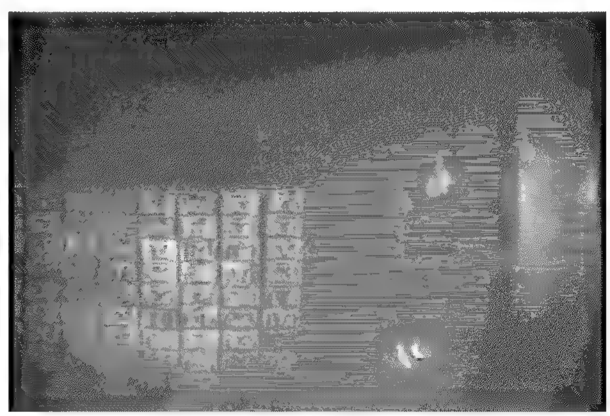


Figure 20: Test 4 Fire, 13 Seconds After Ignition

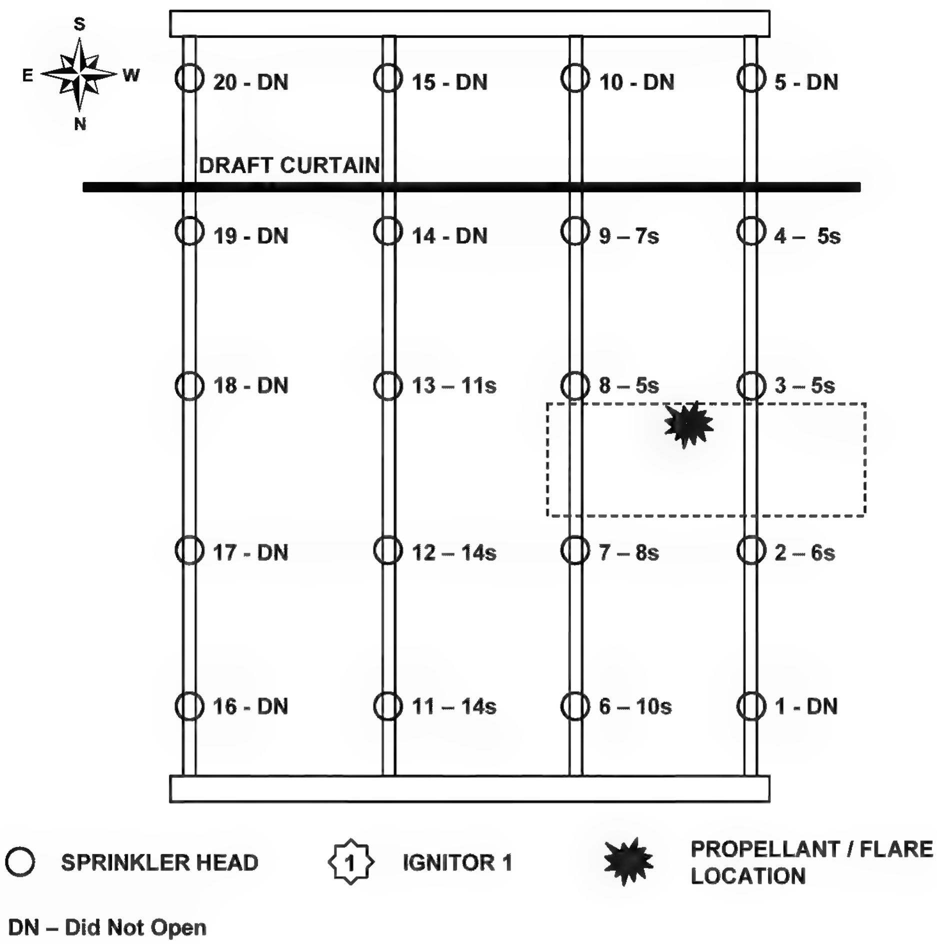


Figure 21: Test 4 Sprinkler Head Time to Open

Note: The length of the draft curtain was extended to 54 inches (1.37 m) below the ceiling before Test #5 due to an excessive amount of hot gases escaping to the adjacent draft curtain area. The original draft curtain length from the ceiling was 30 inches (0.76 m). The draft curtain remained at the 54-inch (1.37 m) length for the remainder of testing.

TEST 5

This test was conducted on 27 March 2001 as described in Scenario 2. Scenario 2 is spontaneous combustion of the donor charge (17 pounds [7.7kg] of unconfined propellant) inside an ammo box. Approximately three gallons of diesel were spilled onto ammo boxes adjacent to the donor charge. An electric match was used to ignite the donor charge. Upon ignition, the propellant produced large jets of fire through the ammo box seams. Flame detector 1 alarmed one second after ignition and detector 2 responded five seconds after ignition. Thirteen sprinklers above and around the donor stack opened within 12 seconds after ignition with the first head opening in four seconds. Water flow was 60

gpm (227 lpm) per head with a flow density of 0.68 gpm/ft.^{2} (27.6 lpm/m^2) on the ammunition stack. The infrared video camera showed the fire continued to burn and faded out two minutes after it was initiated. The fire was contained and did not spread to adjacent ammo stacks. All fusing sprinklers were within the draft curtain containment. Figure 22 below shows the propellant location and the sprinkler opening times.

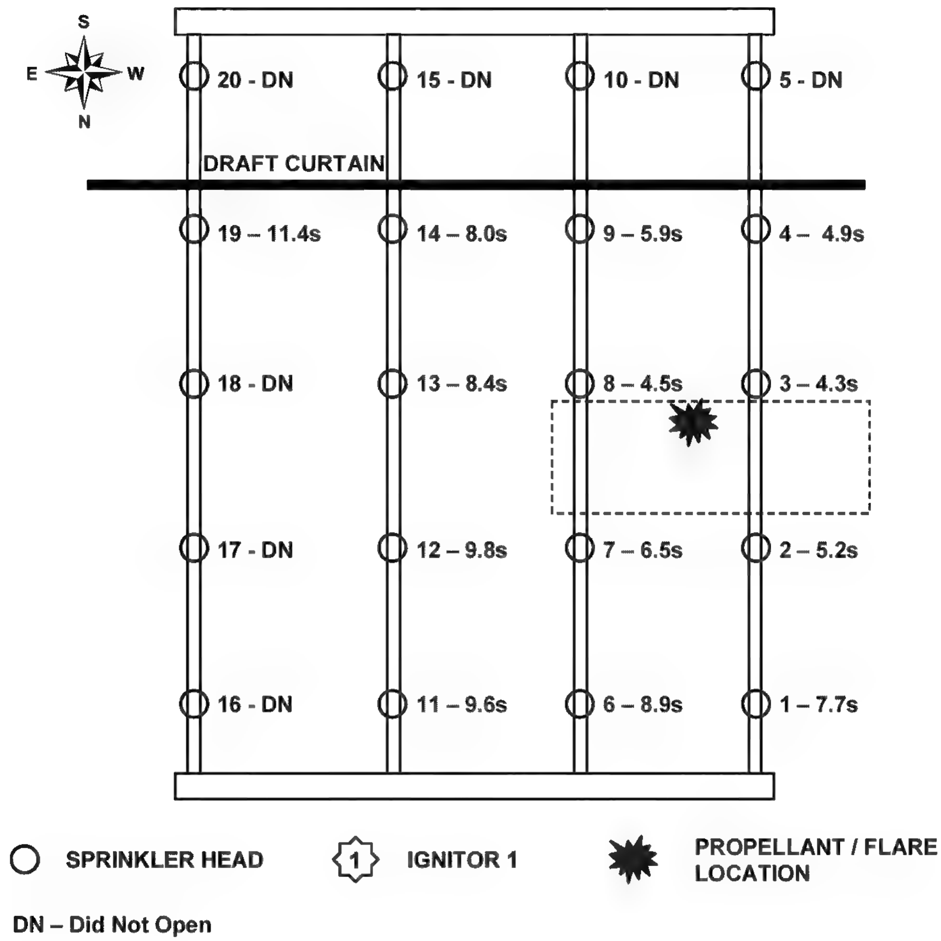


Figure 22: Test 5 Sprinkler Head Time to Open

TEST 6

This test was conducted on 29 March 2001 as described in Scenario 2. Scenario 2 is spontaneous combustion of the donor charge (17 pounds [7.7 kg] of unconfined propellant) inside an ammo box. Approximately three gallons (11.4L) of diesel were spilled onto ammo boxes adjacent to the donor charge. An electric match was used to ignite the donor charge. Upon ignition, the propellant produced large jets of fire through the ammo box seams. A thermocouple in the donor charge box recorded temperatures above 2000°F (1100°C)for seven seconds after ignition.

Flame detector 1 recorded the flame one second after ignition and detector 2 responded five seconds after ignition. Thirteen sprinklers above and around the donor stack opened within 13 seconds after ignition with the first head opening in four seconds. Water flow was 60 gpm (227 lpm) per head with a flow density of 0.68 gpm/ft.^{2} (24.4 lpm/m^2) on the ammunition stack. Results for this test were similar to other scenario 2 evaluations, however unfortunately the video recorders did not record this test. The fire was contained and did not spread to adjacent ammo stacks. All fusing sprinklers were within the draft curtain area. Figure 23 below shows the propellant location and the sprinkler opening times.

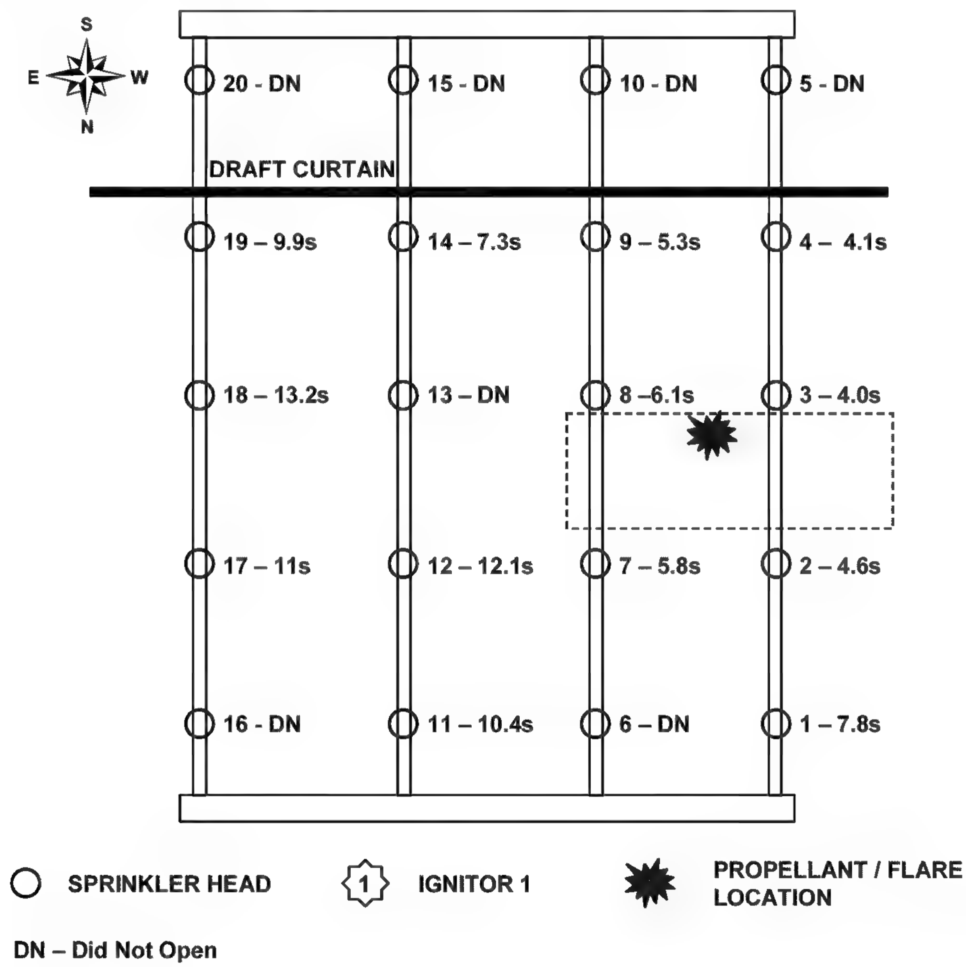


Figure 23: Test 6 Sprinkler Head Time to Open

Figure 24 shows selected contour plots of the ceiling temperatures for Test 6. The plots show the temperature profile at 0.5-second intervals. Each intersection in the plots represents a sprinkler location as shown in Figure 3. These plots have been animated for each test with 1-10 plots

per second and an average of 250 plots per animation. The animations are available from the report authors. Figure 17 shows the temperature scale for the contour plots in Fahrenheit and Celsius degrees. Appendix 1 shows one page of contour plots for each test.

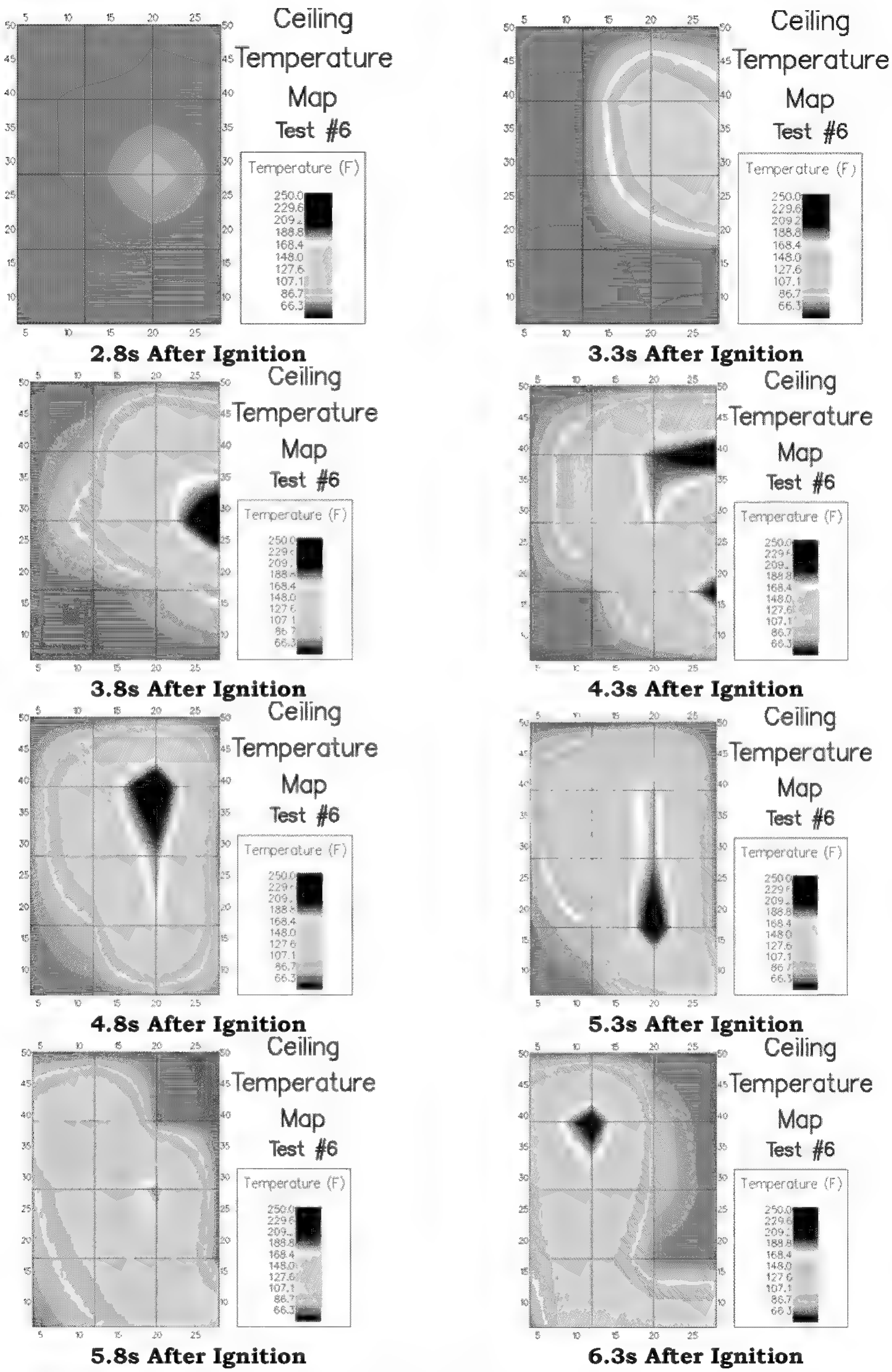


Figure 24: Test 6 Ceiling Temperatures @ 0.5 Second Intervals

TEST 7

This test was conducted on 12 April 2001 as described in Scenario 3. Scenario 3 is the ignition of two illumination canisters, 6.6 pounds (3 kg), from 4.2-inch mortar rounds located inside an ammo box. An electric match was used to ignite the illumination composition. Upon ignition, the illumination composition produced an energetic reaction, blew hot embers from the side of the box and onto the adjacent stack and immediately produced a very intense fire. Flame detector 1 recorded the flame one second after ignition and detector 2 responded seven seconds after ignition. Figure 25 shows the flame five seconds after ignition. Sprinkler three was the only fusing sprinkler, opening 12 seconds after ignition. Water flow was 200 gpm (757 lpm). The infrared video camera shows in Figure 26 that the fire continued to burn intensely after the sprinkler fused. The flames began to die down 45 seconds after ignition and no flames were visible on the IR camera 100 seconds after ignition. The fire was contained and did not spread to adjacent ammo stacks. The fusing sprinkler was within the draft curtain area.

Figure 25: Test 7 Fire, 5 Seconds After Ignition

Figure 26: Test 7 Fire, 30 Seconds After Ignition

Figure 27 shows selected contour plots of the ceiling temperatures for Test 7. The plots show the temperature profile at two-second intervals. Each intersection in the plots represents a sprinkler location as shown in Figure 3. These plots have been animated for each test with 1-10 plots per second and an average of 250 plots per animation. The animations are available from the report authors. Figure 17 shows the temperature scale for the contour plots in Fahrenheit and Celsius degrees. Appendix 1 shows one page of contour plots for each test.

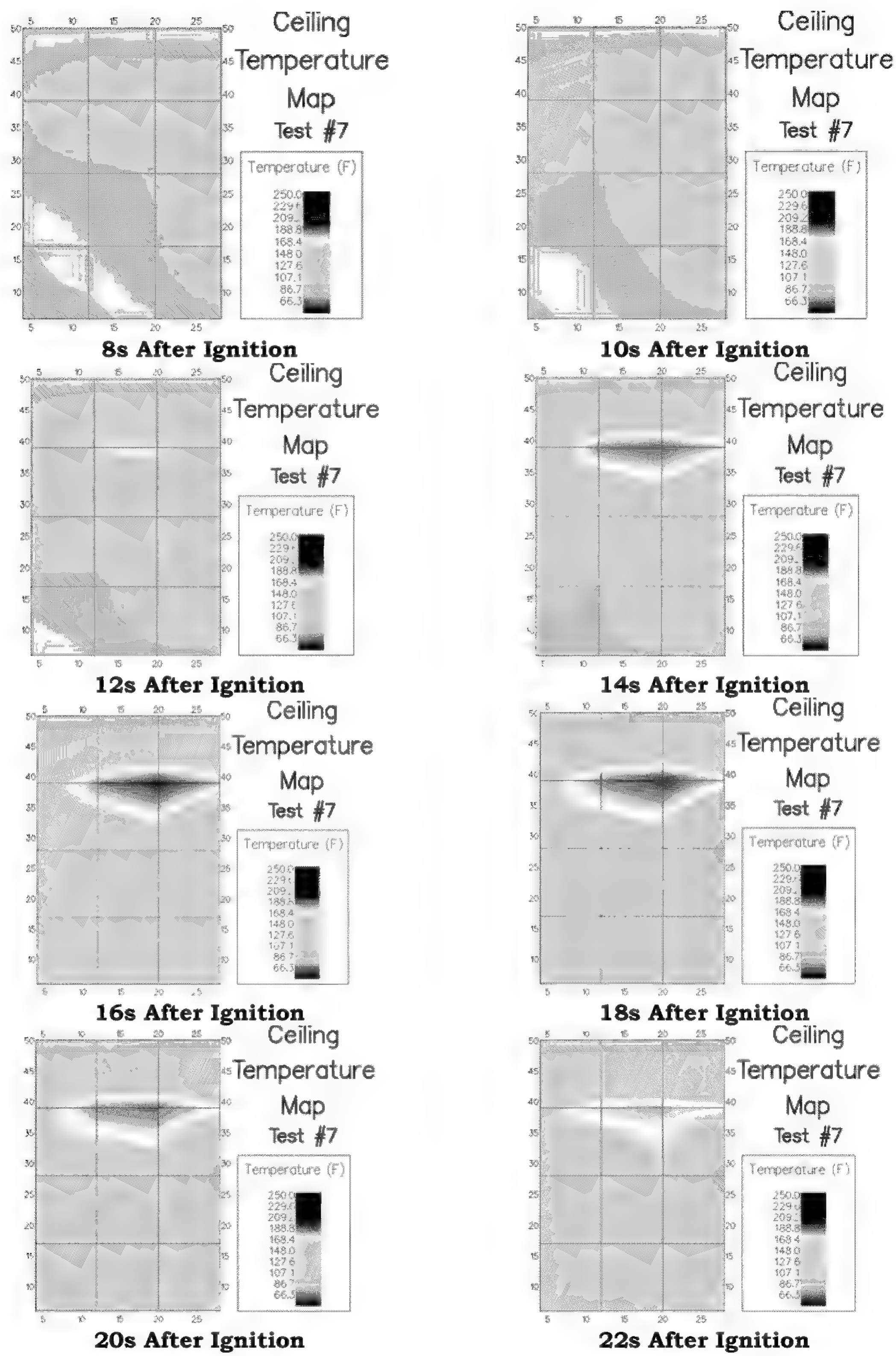


Figure 27: Test 7 Ceiling Temperatures @ 2 Second Intervals

TEST 8

This test was conducted on 19 April 2001 as described in Scenario 3. Scenario 3 is an ignition of two illumination canisters inside of an ammo box. An electric match was used to ignite the illumination composition. The ignition in this test was not as energetic as in Test 7, however, the resulting fire was just as intense. Flame detector 1 recorded the flame one second after ignition and detector 2 responded eight seconds after ignition. Sprinkler 3 was the only fusing sprinkler, opening 12 seconds after ignition. Water flow was 250 gpm (946 lpm). Again, the fire intensity began to decrease 45 seconds after ignition and was extinguished 120 seconds after ignition. The fire was contained and did not spread to adjacent ammo stacks. The fusing sprinkler was within the draft curtain area.

TEST 9

This test was conducted on 30 April 2001 as described in Scenario 3. Scenario 3 is ignition of two illumination canisters inside of an ammo box. An electric match was used to ignite the IR flare. The ignition of the flare was energetic as in Test 7 and the flame intensity was similar to Tests 7 and 8. Flame detector 1 recorded the flame one second after ignition and detector 2 did not alarm during the test due to the fire being located behind an obstruction. Sprinklers 3 and 9 opened 16 seconds after ignition. Water flow was 175 gpm (662 lpm) per head. The flame began to decrease in intensity 50 seconds after ignition and was extinguished at 85 seconds. The fire was contained and did not spread to adjacent ammo stacks. All fusing sprinklers were within the draft curtain area. The donor box containing the illumination composition is shown post-test in Figure 28.

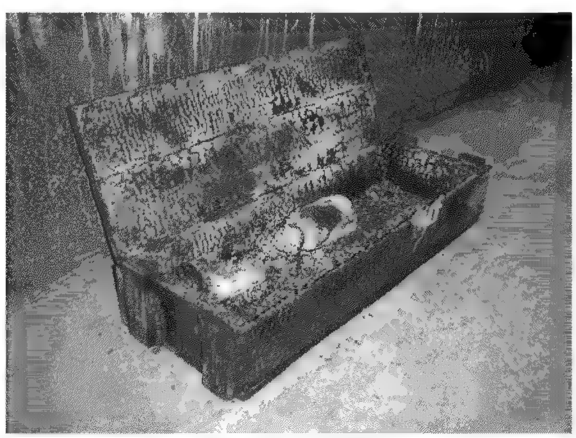


Figure 28: Test 9 Donor Box Post-test

TEST 10

This test was conducted on 17 April as described in Scenario 1 with the modification of igniting the propellant after the first sprinkler opened and

was a repeat of the events of Test 2. Five gallons (18.9L) diesel fuel were spilled around stack 2. Igniters #1 and #2 were located in the diesel spill, one on the side of the stack near the donor charge and one in the front of the stack as shown in Figure 3. The third ignition source was placed inside of the donor charge. The primary match and secondary matches were initiated to start the fire. They produced a diesel fuel fire that in time propagated to the ammo boxes. Flame detector 1 alarmed two seconds after ignition and detector 2 responded four seconds after ignition. The fire resulted in a single sprinkler opening, sprinkler #8, 46 seconds after ignition. This sprinkler controlled the fuel and ammo box fire. Ten seconds after the sprinkler opened, the 17 pounds (7.7 kg) of propellant (donor charge) were ignited with an electric match by the test director. The fire from the propellant was very intense and in a matter of seconds caused seven more sprinklers to open (numbers 1, 2, 3, 4, 7, 9 and 14) controlling the fire within 15 seconds. The flames impinged on stack 3 for seven seconds after the donor charge was initiated. The IR camera showed that some hot gases from the propellant burn penetrated two rows into the adjacent ammo box stack, however this was short duration (~ 10 seconds) and no flames were seen in the adjacent stack. Water flow rate was 95 gpm (360 lpm) per head, and the flow density on the munitions stack 2 was 1.08 gpm/ft.^{2} (43.9 lpm/m^2). The water contained the fireball and kept the fire from spreading. The external fire was extinguished 15 seconds after donor charge ignition and the donor charge was quenched 45 seconds after ignition. Adjacent ammo stacks were not damaged. Figure 29 shows the igniter locations and the sprinkler opening times.

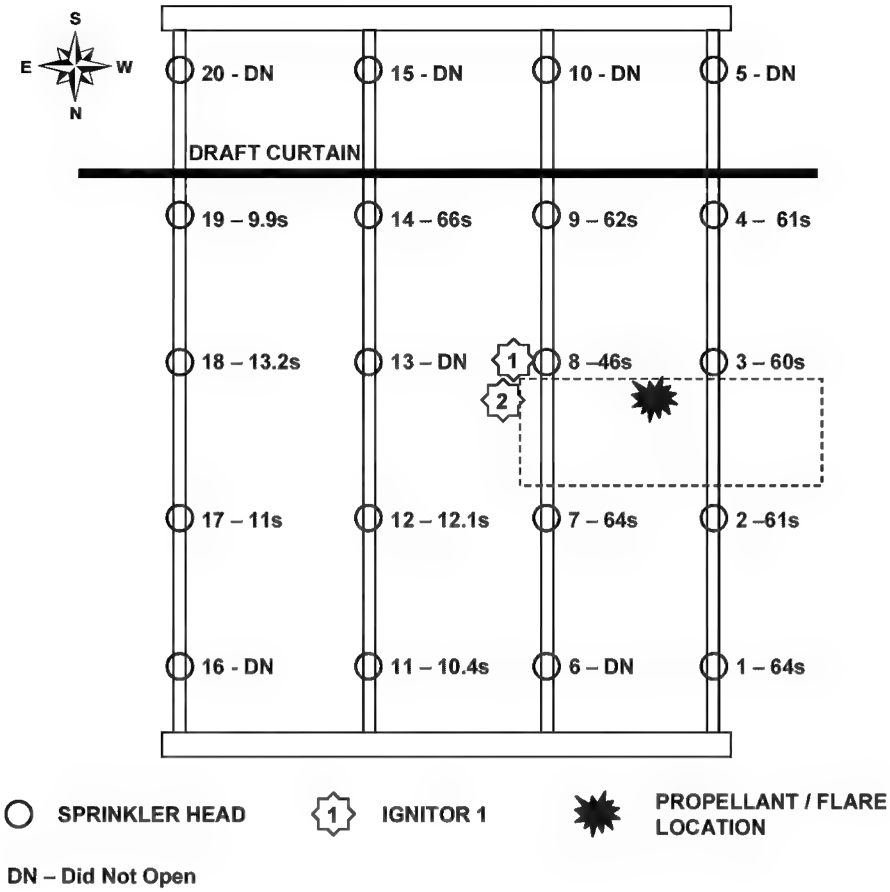


Figure 29: Test 10 Sprinkler Head Time to Open

TEST 11

This test was conducted on 3 May 2001 and was a new scenario, not described in the test plan, performed at the request of the technical advisor Mr. Bob Loyd. Boxes were stacked five high X five wide X four deep (Figure 30). Propellant and illumination composition were placed in the bottom middle ammo box (2 pounds [0.9 kg] of JA-2 propellant, 5 pounds [2.3 kg] of LKL propellant, 13 pounds [5.9 kg] of M1 propellant, and 6.6 pounds [3 kg] of illumination composition). This test evaluated the sprinkler system effectiveness on a fire originating at the bottom of an ammo box stack.

After ignition, the fire was immediately very intense and engulfed the entire stack and the empty spaces between adjacent stacks Figure 31). Sprinklers began to fuse in the first three seconds and 15 sprinklers opened within 14 seconds after ignition. Each sprinkler flowed 50 gpm (189 lpm) with a flow density of 0.57 gpm/ft.^{2} (23.2 lpm/m^2) on the ammunition stack. Within the first 20 seconds, ceiling temperature exceeded 300°F (177°C) at sprinkler 2 and 500°F (260°C) at sprinkler 4.

Three ceiling thermocouples were still measuring ceiling temperatures above 150°F (66°C) 60 seconds after ignition. However, the fire was contained to the ignition stack with a majority of the ammo boxes showing no flame damage. Only boxes in the immediate vicinity of the donor box were damaged. Figure 32 and Figure 33 show the damage to the ammo boxes located near the donor box. Figure 34 shows the remainder of the donor box. The IR camera indicated that the fire was out 100 seconds after ignition. Adjacent ammo stacks had no damage. All fusing sprinklers were within the draft curtain area. Figure 35 shows the propellant and illumination composition location and the sprinkler opening times.

Figure 30: Pre-test View

(Before Propellant and illuminations canister Ammo Box Placed)

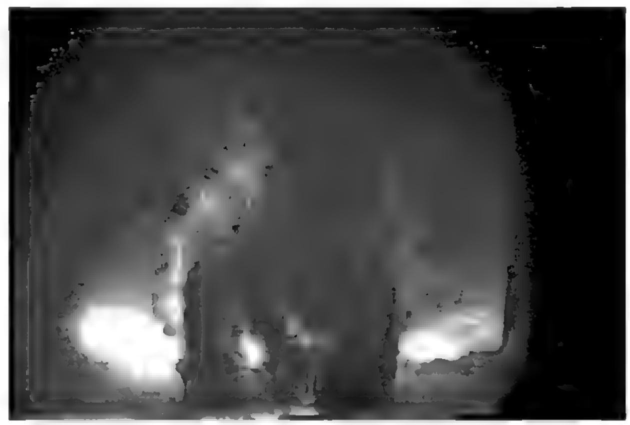


Figure 31: Test 11 Fire, 5 Seconds After Ignition

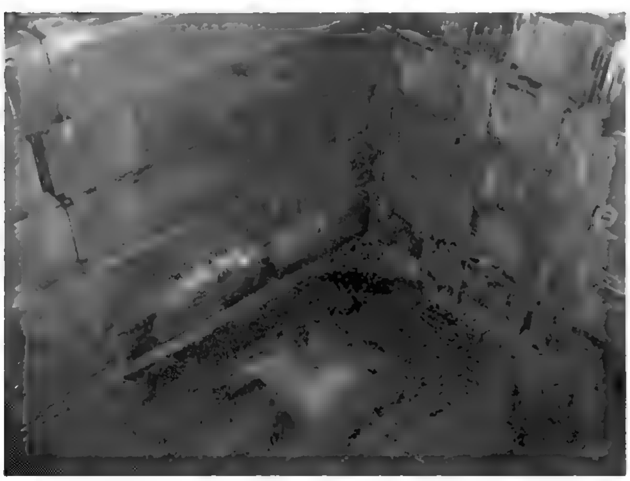


Figure 32: Post-test View

(Propellant and illumination canister Ammo Box Removed)

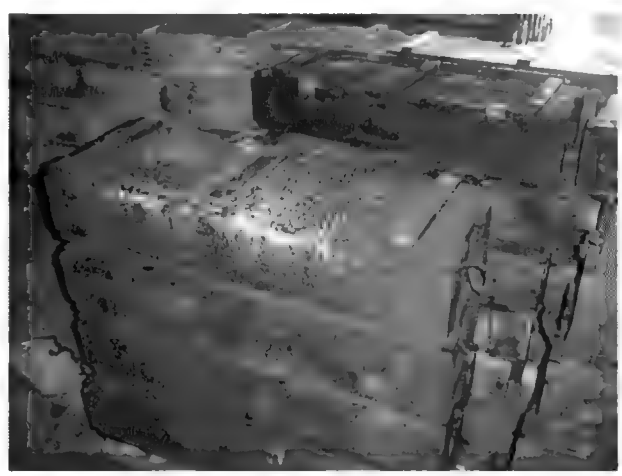


Figure 33: Post-test Inverted Stack of Boxes

(Originally on top of Propellant Ammo Box)

Figure 34: **Post-test Propellant and illumination composition Ammo Box**

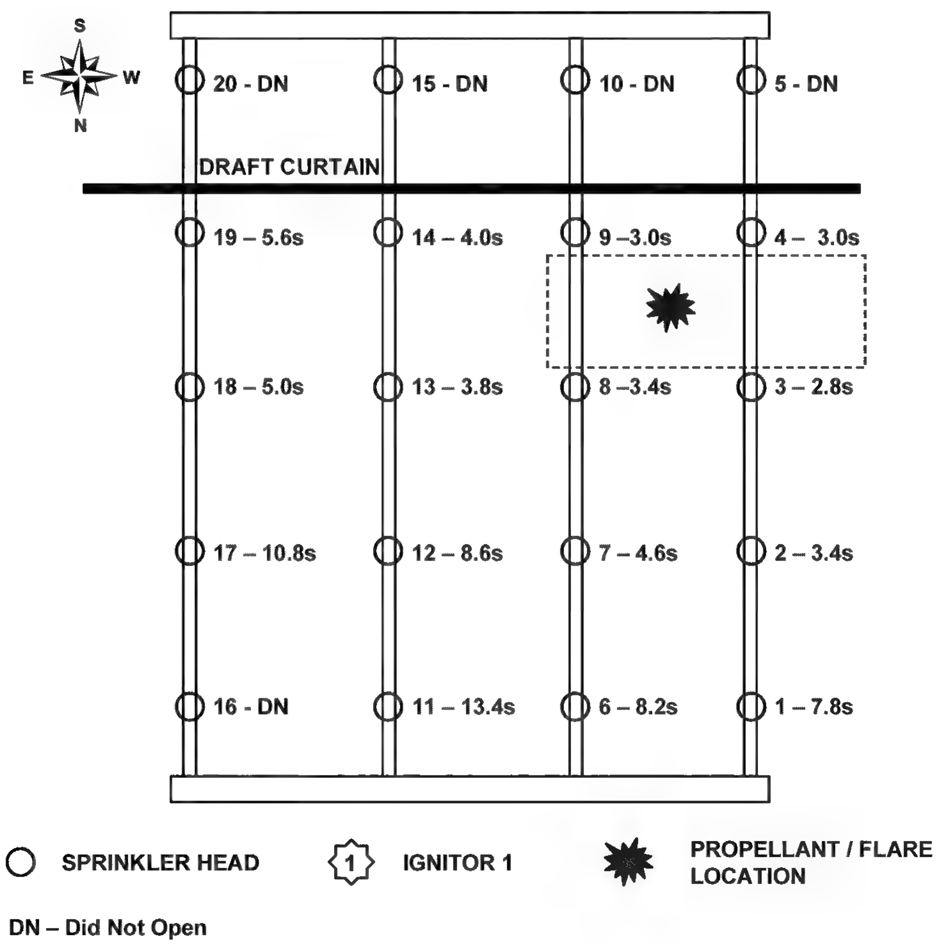


Figure 35: Test 11 Sprinkler Head Time to Open

SECTION IV - CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

1. The ESFR K-25, 165°F (74°C) pendant sprinkler heads will operate and inhibit fire spread when exposed to the types of fires conducted in this test series. The system will rapidly and thoroughly wet the storage boxes to extinguish and contain fires.

2. The sprinkler system evaluated will contain a diesel fuel spill fire and minimize the resulting damage to ammunition storage containers and the facility.

3. A spontaneous combustion fire of 17 pounds of propellant can be limited to the ammunition box of origin and adjacent boxes.

4. The sprinkler system will not extinguish the illumination canisters, however, it will contain the fire, protect surrounding ammunition boxes and prevent fire spread to adjacent ammunition stacks.

5. A draft curtain will prevent excess sprinklers from opening. No sprinklers outside the draft curtain containment opened during the tests.

6. The optical flame detectors used in the tests could be valuable for detecting fires and initiating an alarm system in munitions storage locations. These detectors responded in less than five seconds to each fire when the field of view of the detector was unobstructed.

RECOMMENDATIONS

1. Recommend the K-25 sprinkler system, as tested in these evaluations, be installed for protection of stacked box ammunition storage areas. In each test the fire was controlled, extinguished and did not spread to adjacent stacks.

2. In this test series, it was determined that the water application rate tested was more than adequate to control the fires and to prevent the fire spread to adjacent stacks. To optimize the suppression system however, additional tests can determine the minimum required application rate for controlling these fire scenarios. Future evaluations should consider other evaluations of the K-25 and K-17 sprinkler heads and the use of water mist technology. Suggest future evaluations be conducted to include the following:

a. Additional scenarios (only three were conducted in these evaluations)

b. Vary locations of donor/acceptor charges (i.e. center of stacks, closer together, etc.)

c. Vary pressures/flow rates. Lower flow rates/pressures may save substantial amounts of water, pipe size and pump capacity.

d. Evaluation of upright K-25 sprinkler heads vs. pendant K-25 sprinkler heads. Future tests might also include support beams or other equipment that might obstruct the sprinkler heads (as found in real world storage compartments).

3. In the test series using flowing fuel on the floor, it became apparent that the use of pallets would allow the burning fuel to flow under the stacks making it difficult to extinguish the fires. However, with the boxes sitting directly on the floor, the fuel was contained to the edge of the boxes permitting easy containment by the overhead sprinklers. Although it is easier to move the stacks on pallets, recommend for fire control that the boxes be placed directly on the floors. Recommend this situation be examined in future evaluations.

4. This evaluation series did not examine disposal of the copious amounts of water generated on the floor surrounding the test stacks. In real situations the slope of the floor and a collection of the discharged water will be important considerations. Recommend this situation be examined in future evaluations.

5. Recommend the use of draft curtains such as the 54” (137 cm) steel curtain used in the evaluations. The curtain prevented excess sprinklers from opening as no sprinklers outside of the draft curtain area opened during the tests.

ADDITIONAL COMMENTS AND SUGGESTIONS

In addition to the recommendations above, the following points are in this report as observations, comments or suggestions.

1. Copious amounts of smoke generated in each test necessitated the use of IR cameras to determine what was occurring in the fire area both during and after a fire scenario. Where resources permit, underground storage areas should be equipped with CCTV and IR cameras to facilitate actual observation of a fire scenario. In addition, a smoke removal system should be considered in such situations.

2. In actual situations, consider feeding the water supply system from two remote locations (opposite ends) and other means to reduce the vulnerability of the system to accidents. In addition, consider the use of (ARMCO) barricades and smoke doors/separations within the storage area.

3. The storage of ammunition on pallets loaded in MILVANs or CONEX containers is a common practice often used for combat units deploying to the field. These containers could hold non-compatible ammunition items such as white phosphorus projectiles and mortar rounds. This study does not address the issue of the storage of ammunition in MILVANs or CONEXs, however, the threat should be evaluated in future studies. Fire detection and suppression inside the shipping containers that permit quick and easy connections and disconnections, such as from a manifold system, will be needed. Some types of ammunition will also require special arrangements (e.g. The only way to stop burning white phosphorus is to deprive it of air such as by covering it with water).

4. Fire modeling, in future evaluations of potential fires in underground munitions storage areas, could produce a better understanding of the fire dynamics of burning propellants and pyrotechnics.

    a. "Modeling Missile Propellant Fires in Shipboard Compartment", by Derek A. White, Craig L. Beyler, Fredrick W. Williams, and Patricia A. Tatem, published in the Fire Safety Journal discussed this issue. A modified version of FAST, an existing computer fire model, takes into account the fire phenomena specific to missile propellant combustion. The modified computer program and the developed missile propellant burning rate algorithm corrected predicted the results of full-scale burn tests. (Fire Journal, #34 (2000) 321-341).

    b. Recent DOD Explosives Safety Seminars that touch on this area:

        - Potential Fire and Explosion Hazards of a Range of Loose Pyrotechnic Compositions by Roy Merrifield.

        - Non-Thermal Effects From Hazard Division 1.3 Events Inside Structures by Mile Swisdak, Jr.

        - Propagation of Firebrands From Burning Ammunition Stacks by Warren W. Hillstrom.

- Prediction Techniques for Overpressure and Thermal Risk From C/D 1.3 Materials During Processing.

- Hazard Division 1.3 Passive Structural Systems Design Guide by Joseph Serna.

- HD 1.3 Quantity-Distance Shorter But Still Safe by Dr. B. Lawton.

- Scaling Studies of Thermal Radiation Flux From Burning Propellants by J. Edmund Hay.

c. The Center for the Simulation of Accidental Fires & Explosives (C-SAFE) is an organization associated with the University of Utah. The goal of C-Safe is to develop the technical capability to simulate accidental fires and explosions involving hydrocarbons, structures, containers and high-energy materials. One of the possible scenarios to simulate is a fire at an explosives manufacturing plant. Recommend contacting this organization as a potential source of information.

5. The NATO Underground Ammunition Storage Subcommittee, the country of Singapore, DOD Explosives Safety Board, and the individual services are very interested in this work and how they can benefit from the information gathered. Recommend submitting a paper on this topic to publications such as: Fire Journal, Fire Technology, Fire Protection Engineering, Safety Professional and similar commercial sector/military publications .

6. Recommend follow-on, larger scale test evaluations, incorporating recommendations and comments in this report, be conducted in the Hanger Facility at the DOD Fire Lab located at Tyndall AFB, FL. This facility has more area and a significantly higher ceiling. In addition, craftsmen and engineers are readily available to retrofit the facility for these additional tests and to provide the analysis necessary for additional documentation and reports.

SECTION V - REFERENCES

1. Central Sprinkler Literature

2. White, Derek A., Beyler, Craig L., Williams, Fredrick W., and Tatem, Patricia A. "Modeling Missile Propellant Fires in Shipboard Compartment". Fire Safety Journal #34 (2000) 321-341.

3. Pabich, Martin J., and Sheppard, David T., "Report of Large-Scale Fire Tests of Retail Shelf Display and Rack Storage of Cartoned Group A Plastics Utilizing Extended Coverage Sprinklers Having a Nominal F-factor of 25.2," UL Report 00NK22528, NC4119, November 2000

4. NFPA 13. Installation of Sprinkler Systems. National Fire Codes. National Fire Protection Association, Inc. Quincy, MA. 1999.

5. NFPA 520. Standard on Subterranean Spaces. National Fire Codes. National Fire Protection Association, Inc. Quincy, MA. 1999.

APPENDIX A

CEILING TEMPERATURE CHARTS

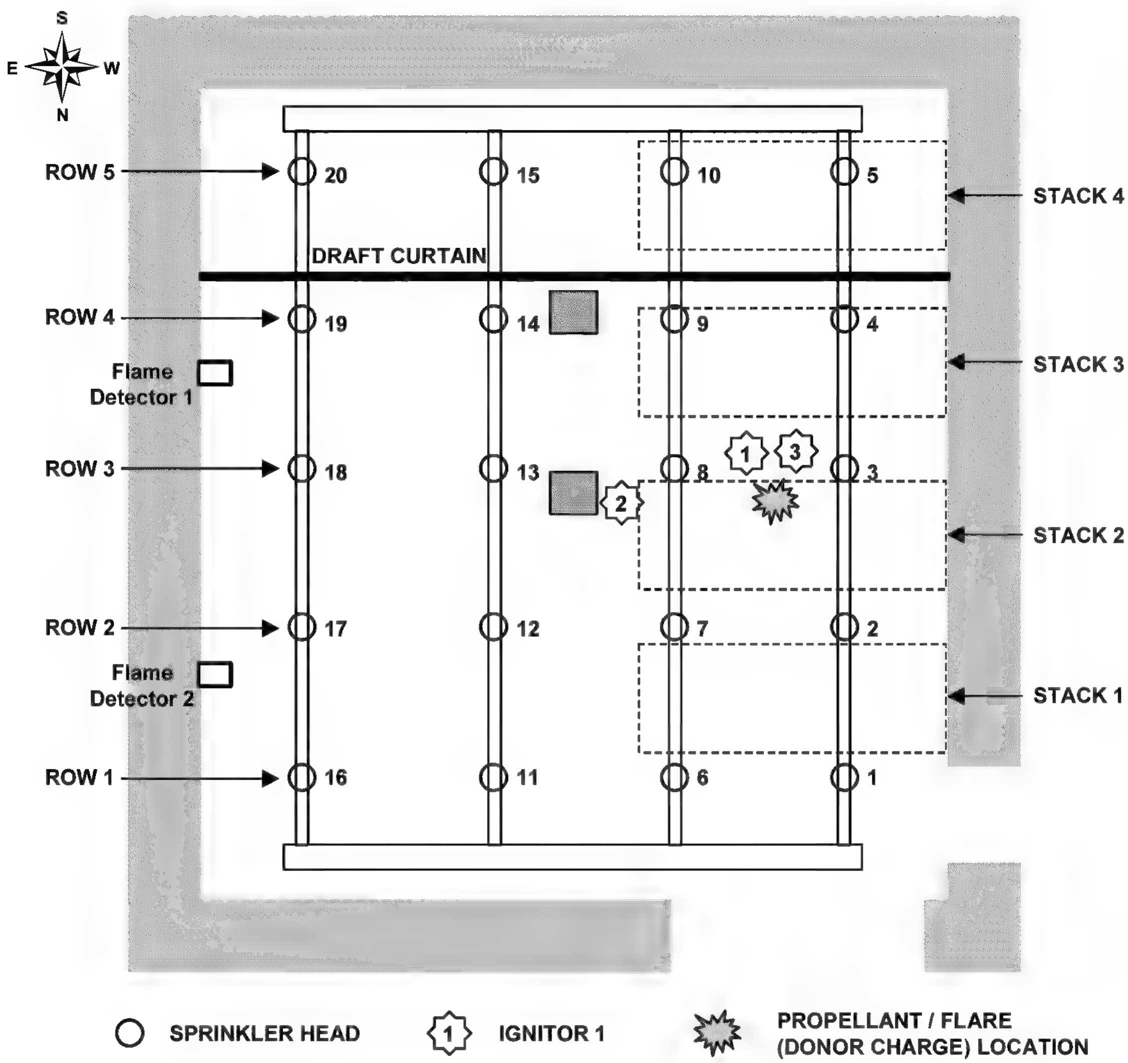


Figure A-1: Facility Arrangement

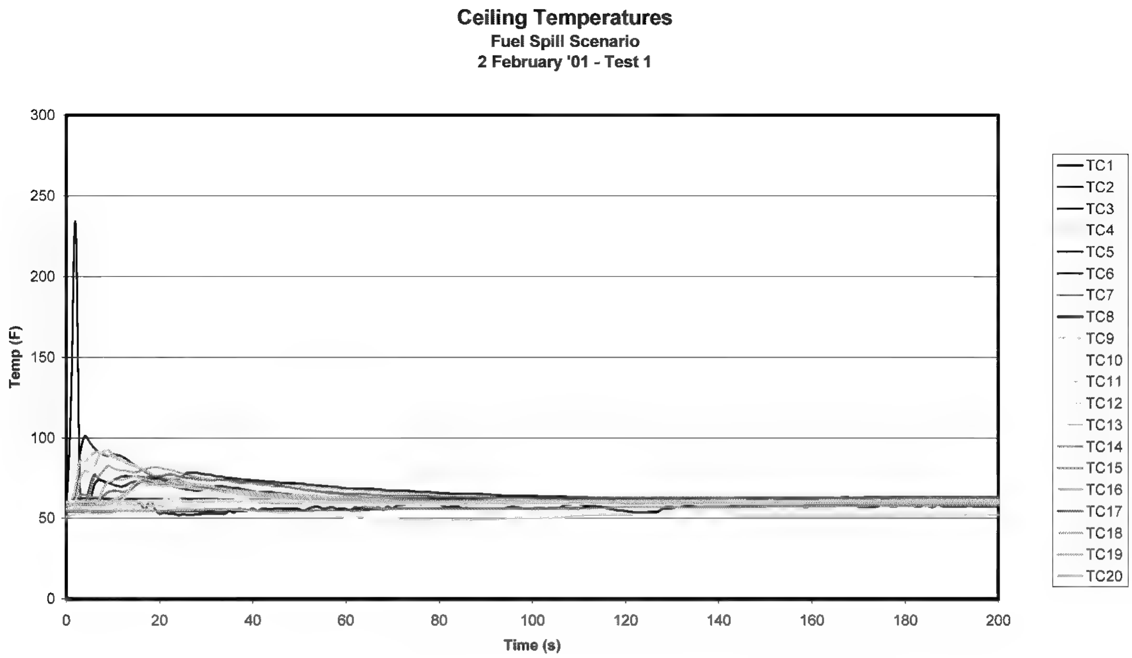


Figure A-2: Test 1 All Ceiling Temperatures

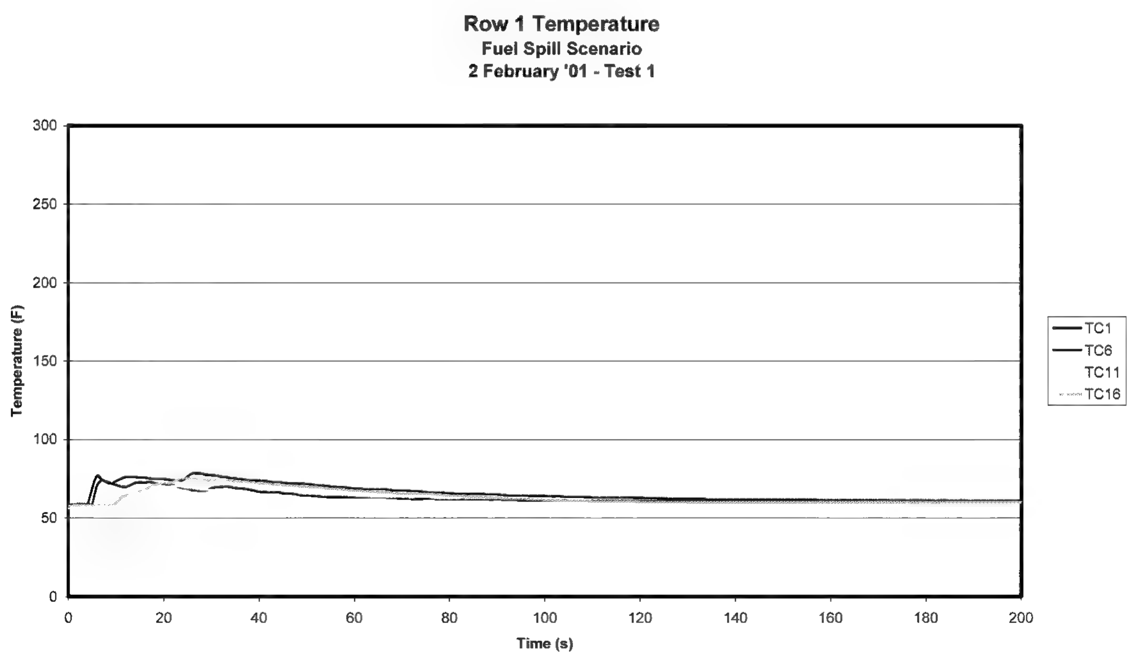


Figure A-3: Test 1 Row 1 Ceiling Temperatures

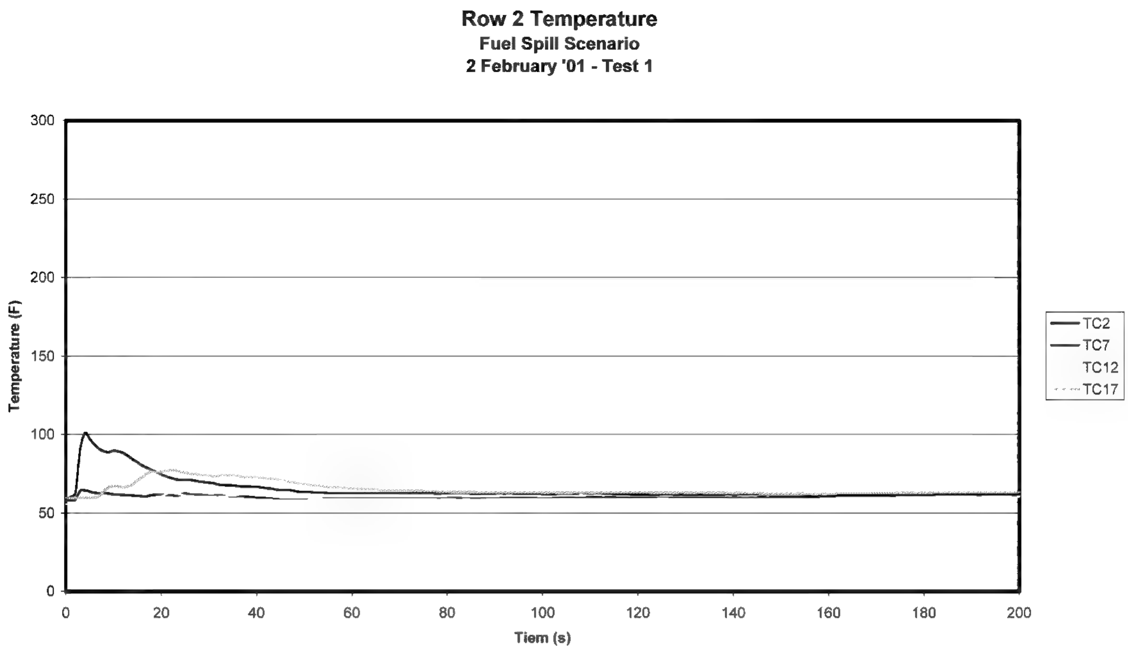


Figure A-4: Test 1 Row 2 Ceiling Temperatures

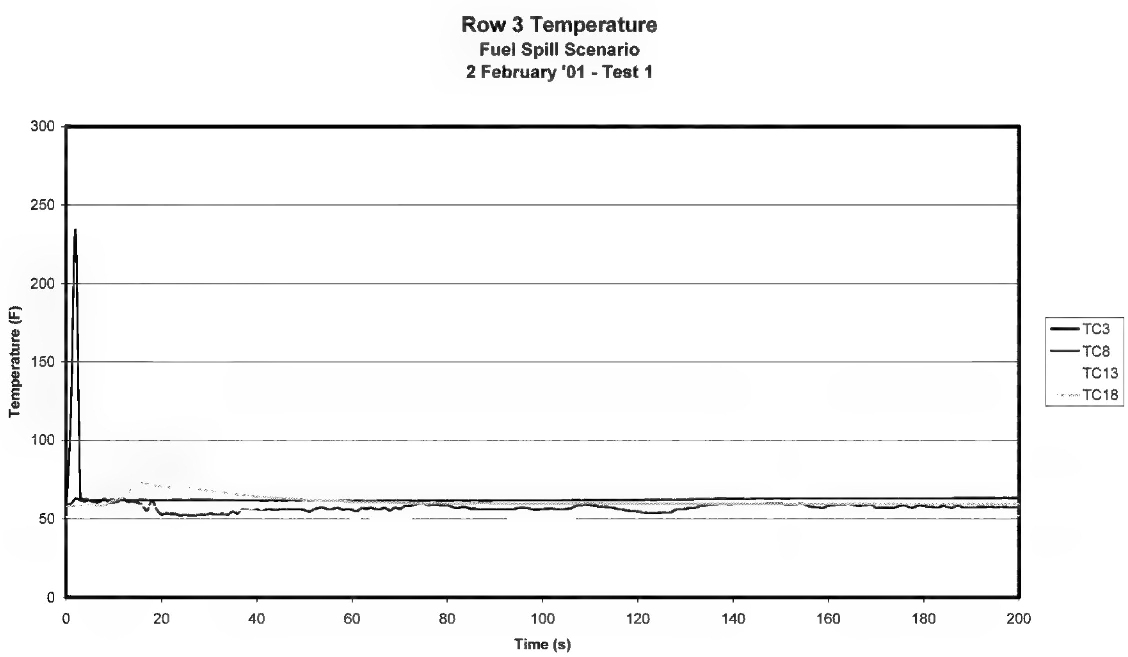


Figure A-5: Test 1 Row 3 Ceiling Temperatures

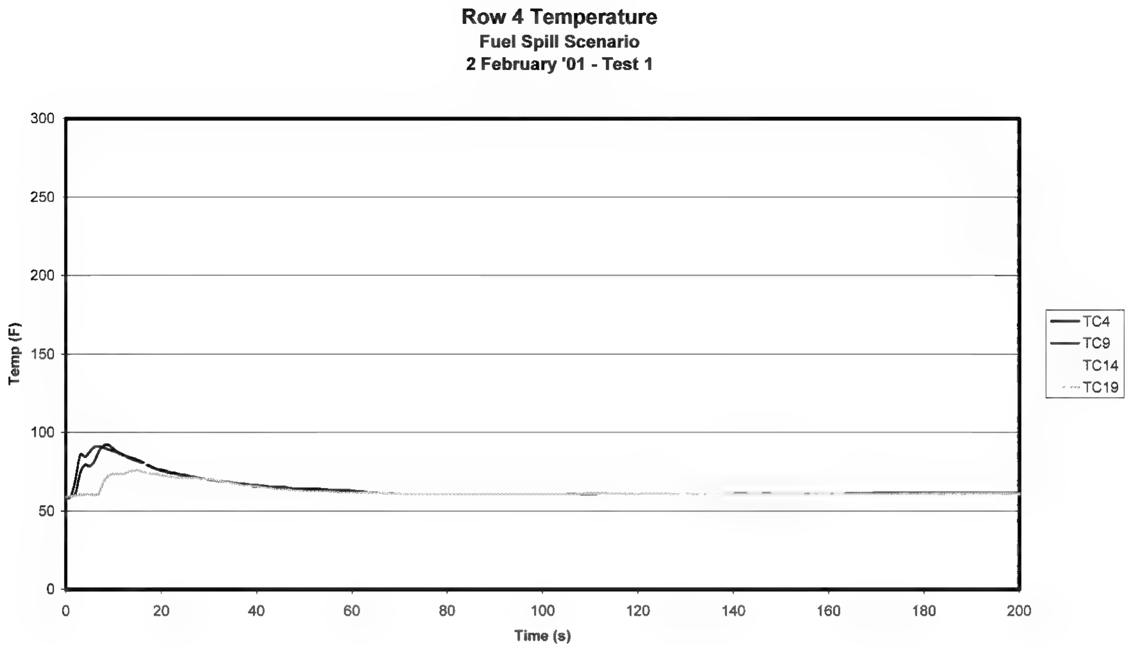


Figure A-6: Test 1 Row 4 Ceiling Temperatures

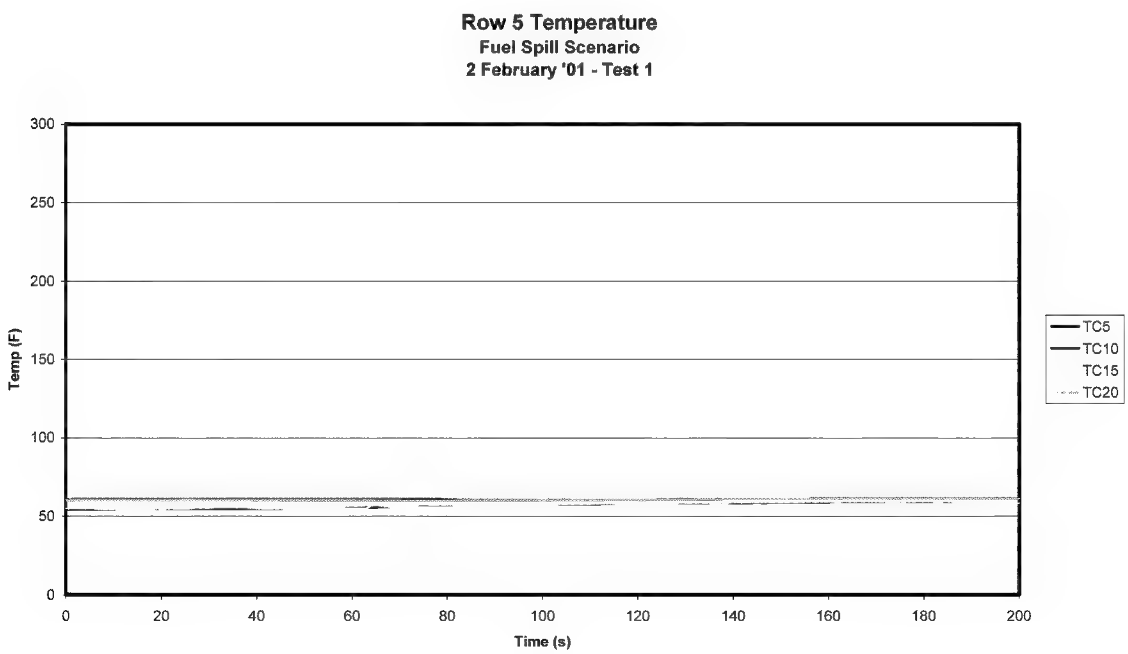


Figure A-7: Test 1 Row 5 Ceiling Temperatures

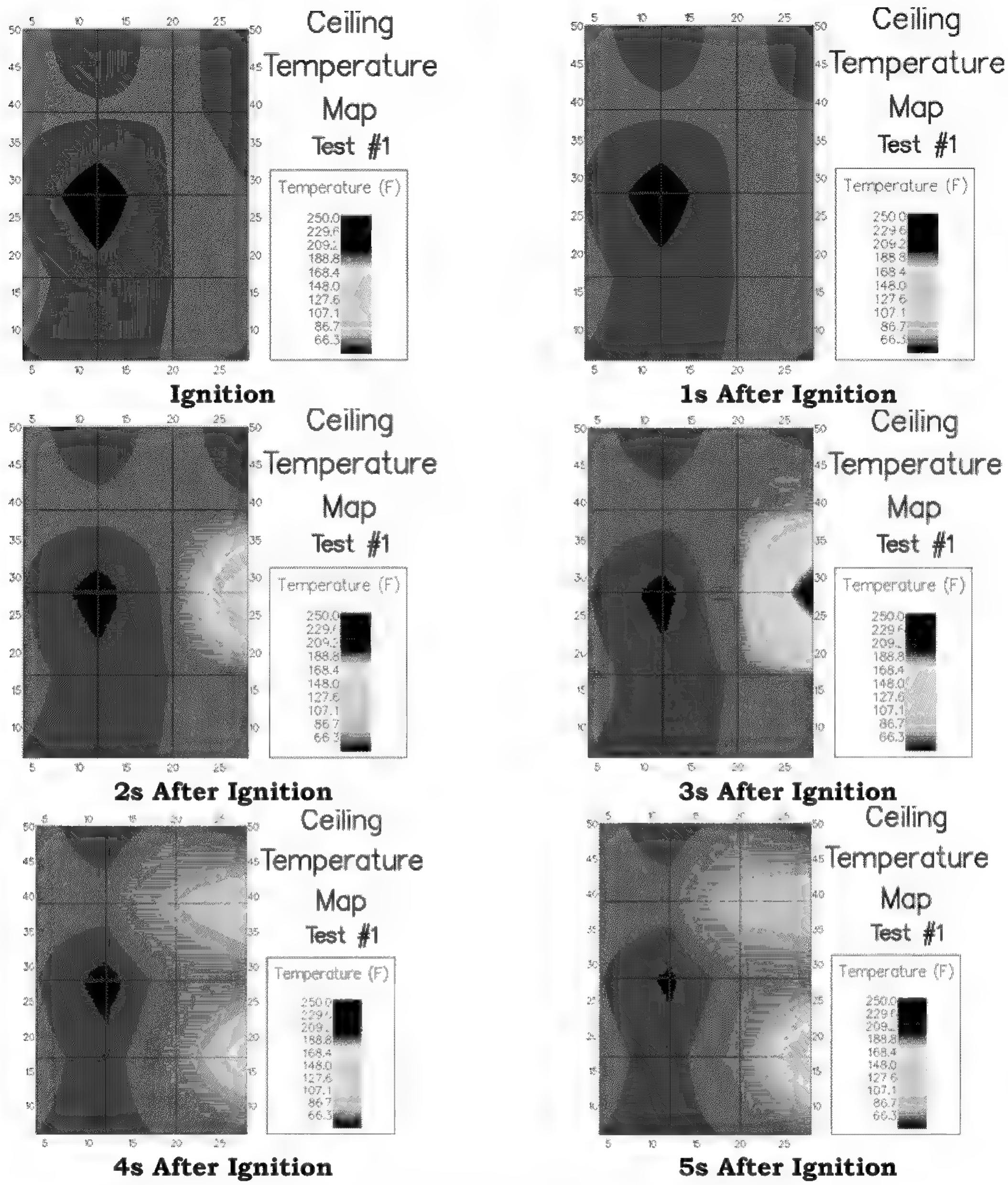


Figure A-8: Test 1 Ceiling Temperatures @ 1 Second Intervals

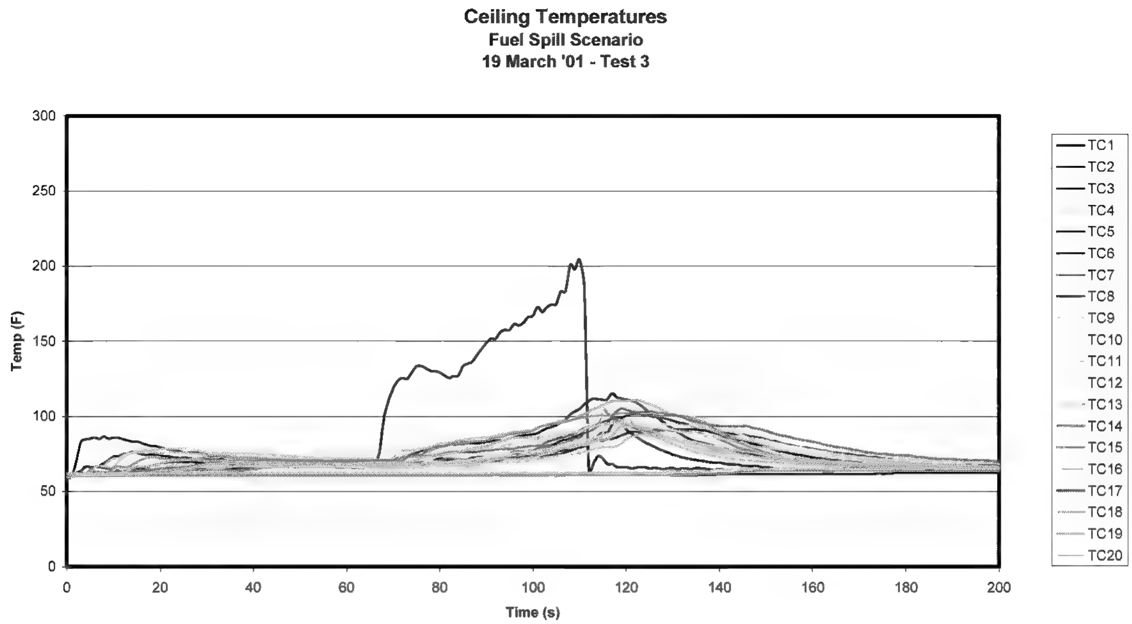


Figure A-9: Test 3 All Ceiling Temperatures

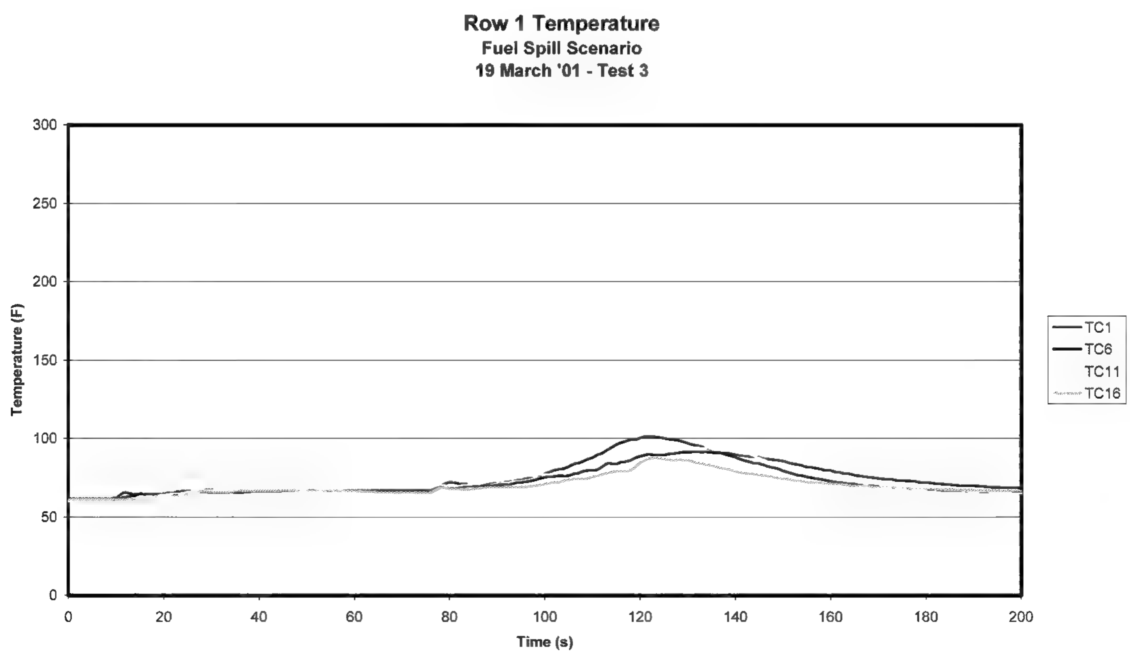


Figure A-10: Test 3 Row 1 Ceiling Temperatures

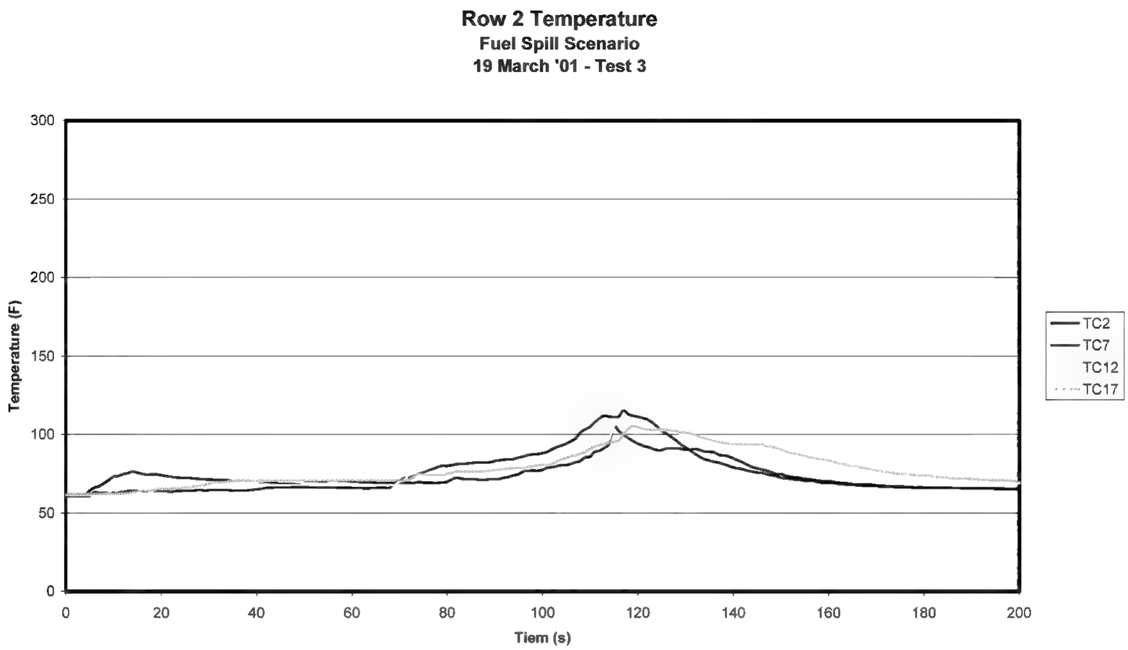


Figure A-11: Test 3 Row 2 Ceiling Temperatures

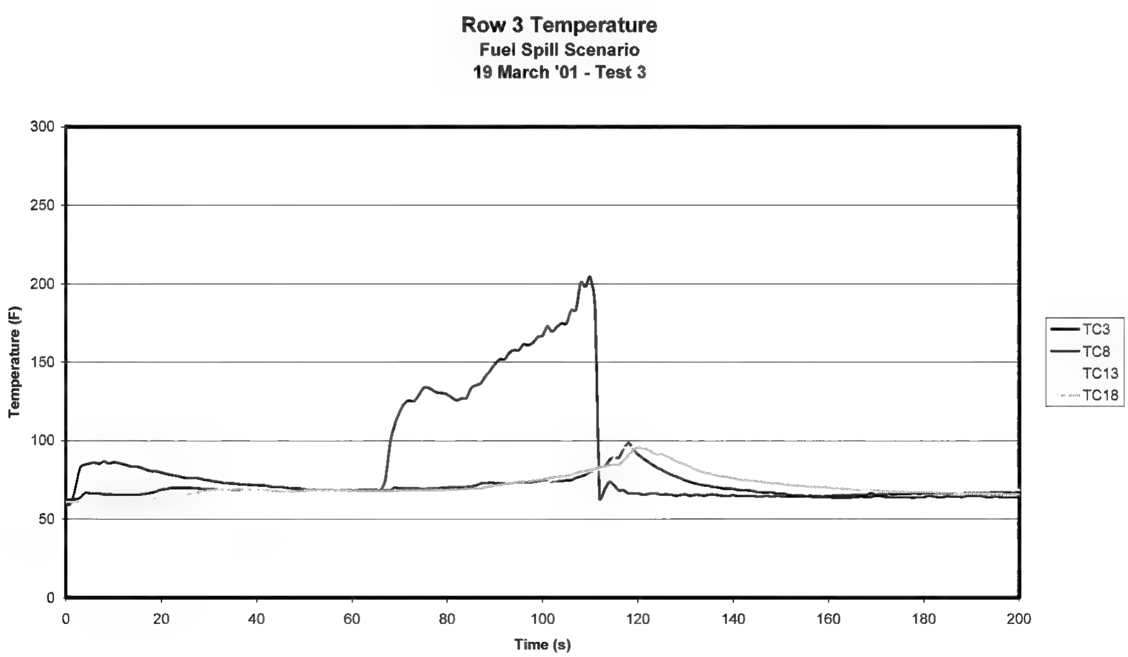


Figure A-12: Test 3 Row 3 Ceiling Temperatures

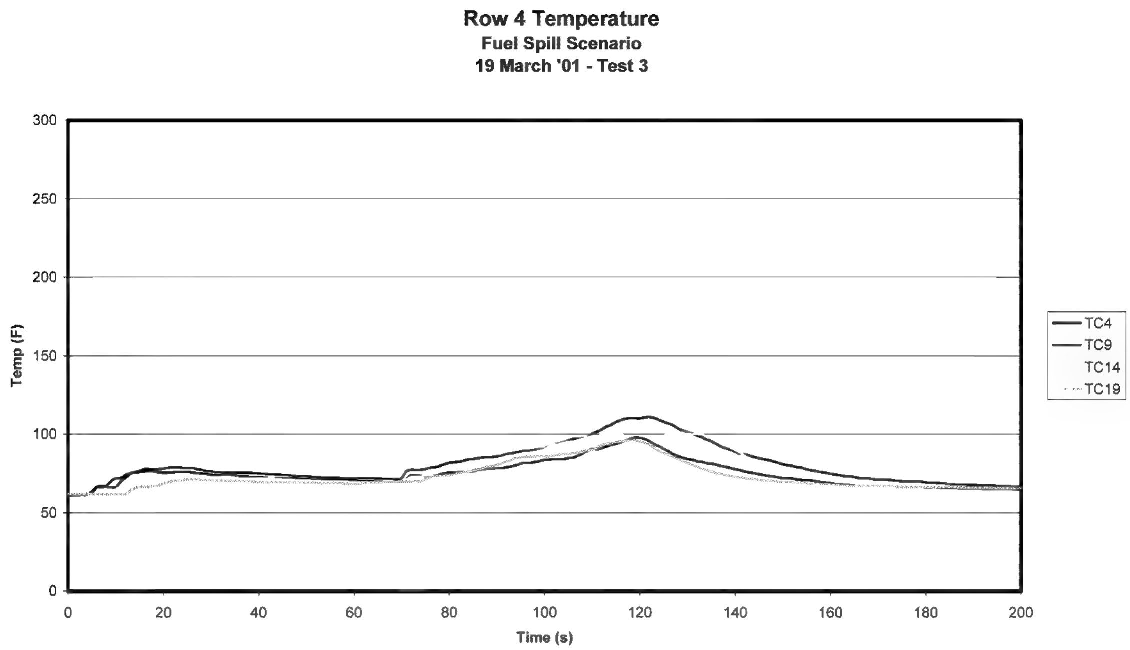


Figure A-13: Test 3 Row 4 Ceiling Temperatures

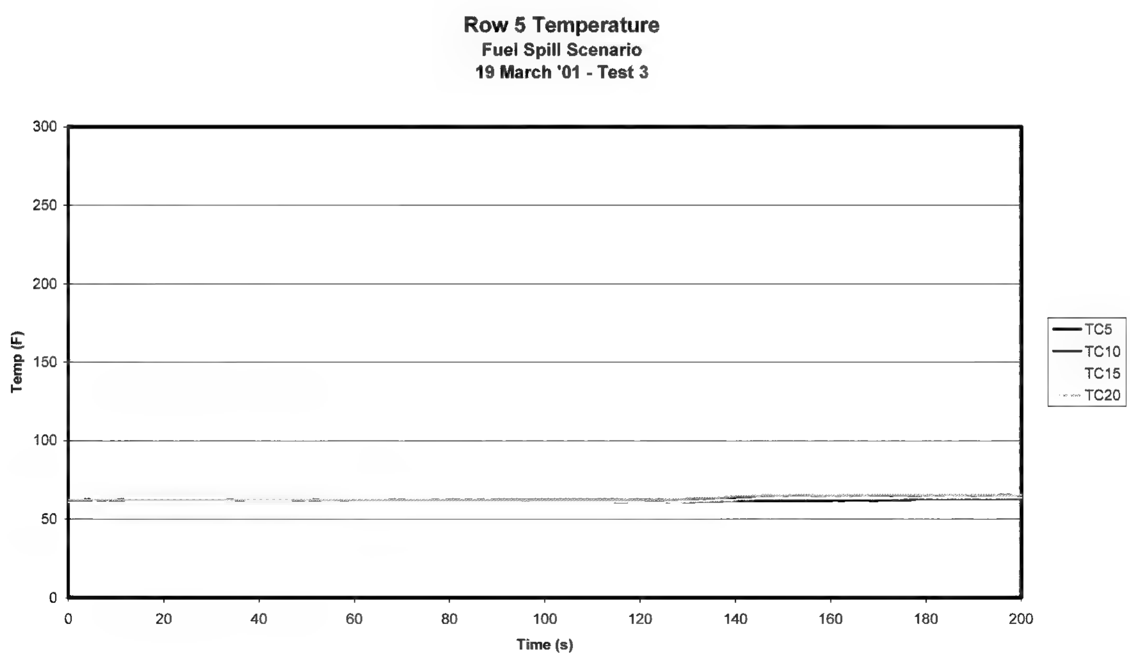


Figure A-14: Test 3 Row 5 Ceiling Temperatures

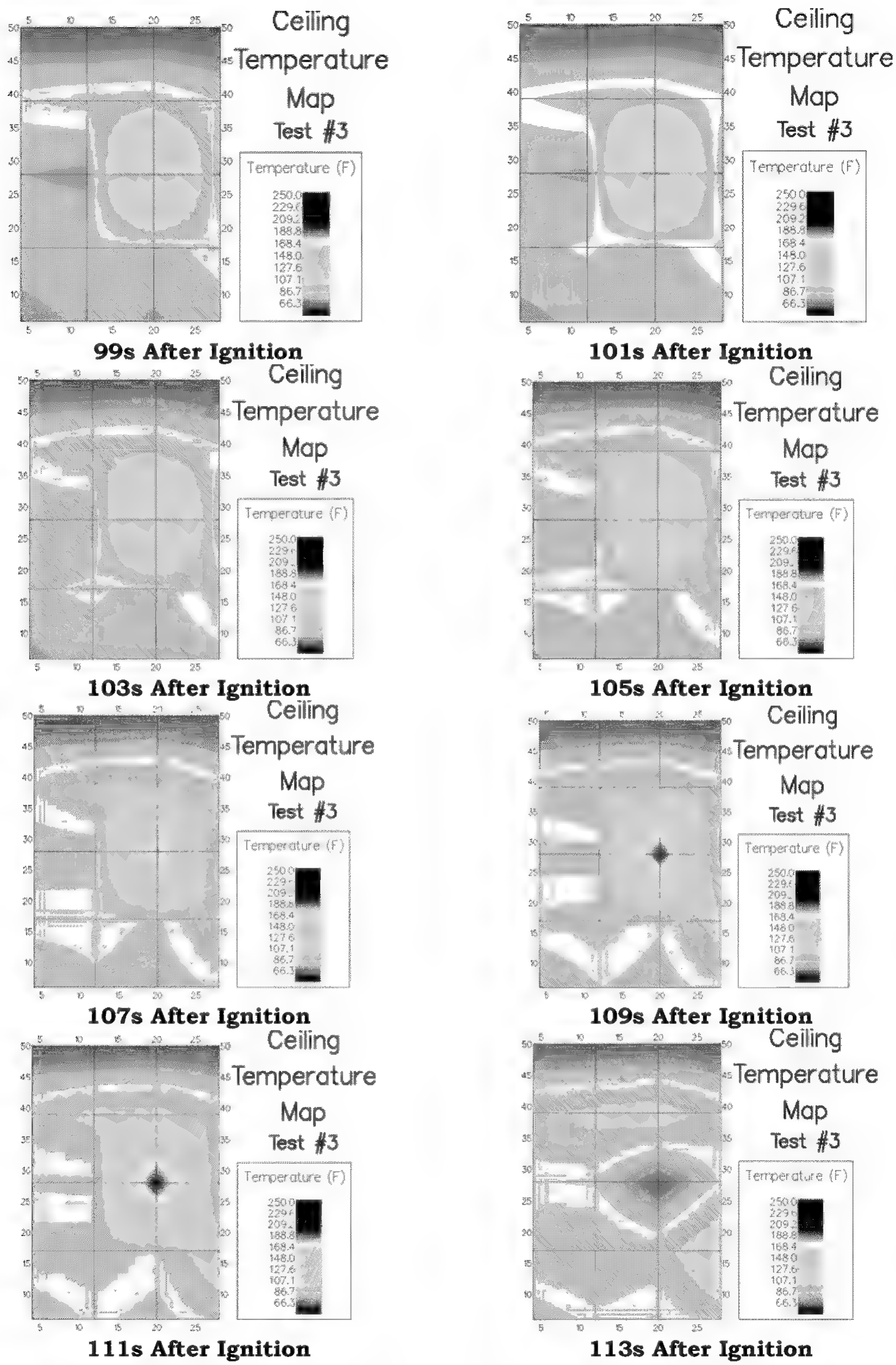


Figure A-15: Test 3 Ceiling Temperatures @ 2 Second Intervals

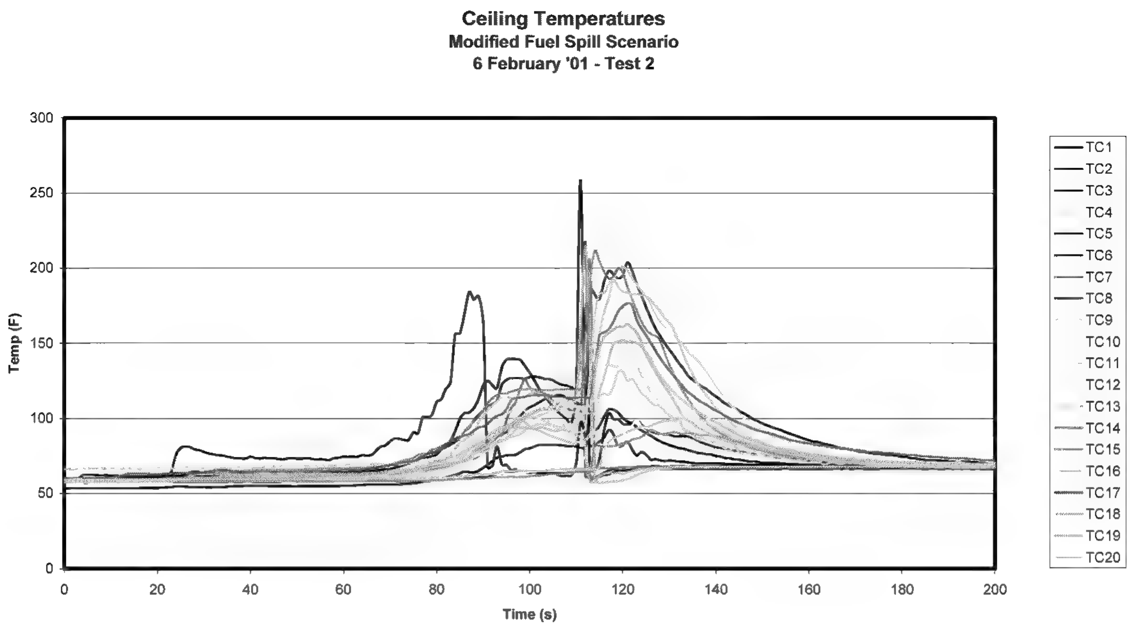


Figure A-16: Test 2 All Ceiling Temperatures

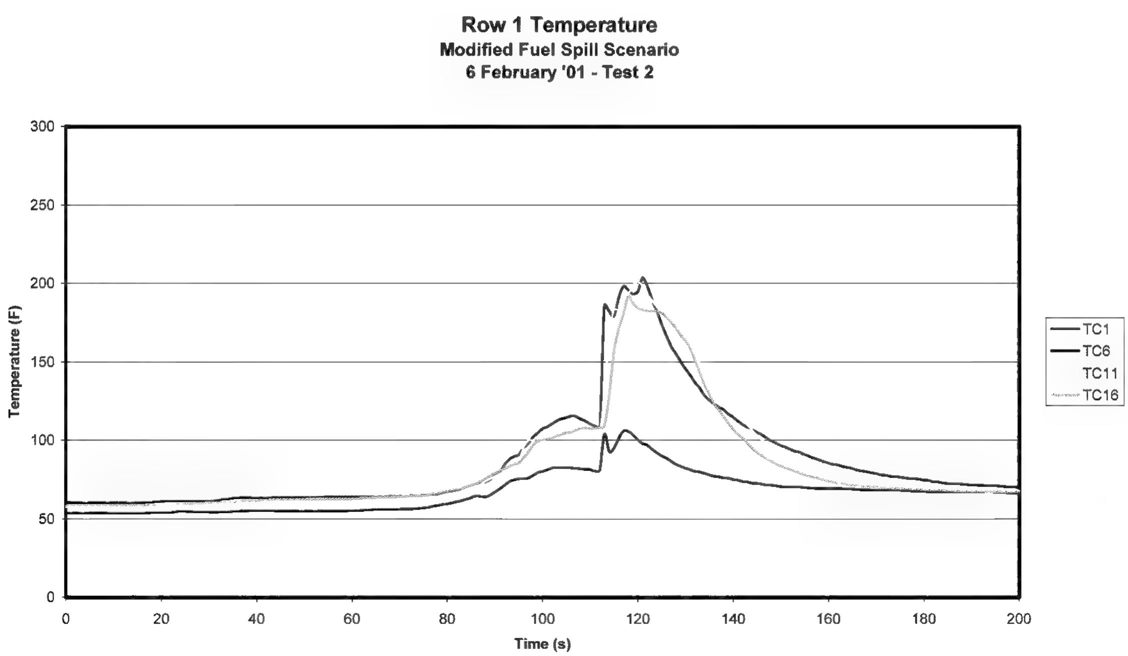


Figure A-17: Test 2 Row 1 Ceiling Temperatures

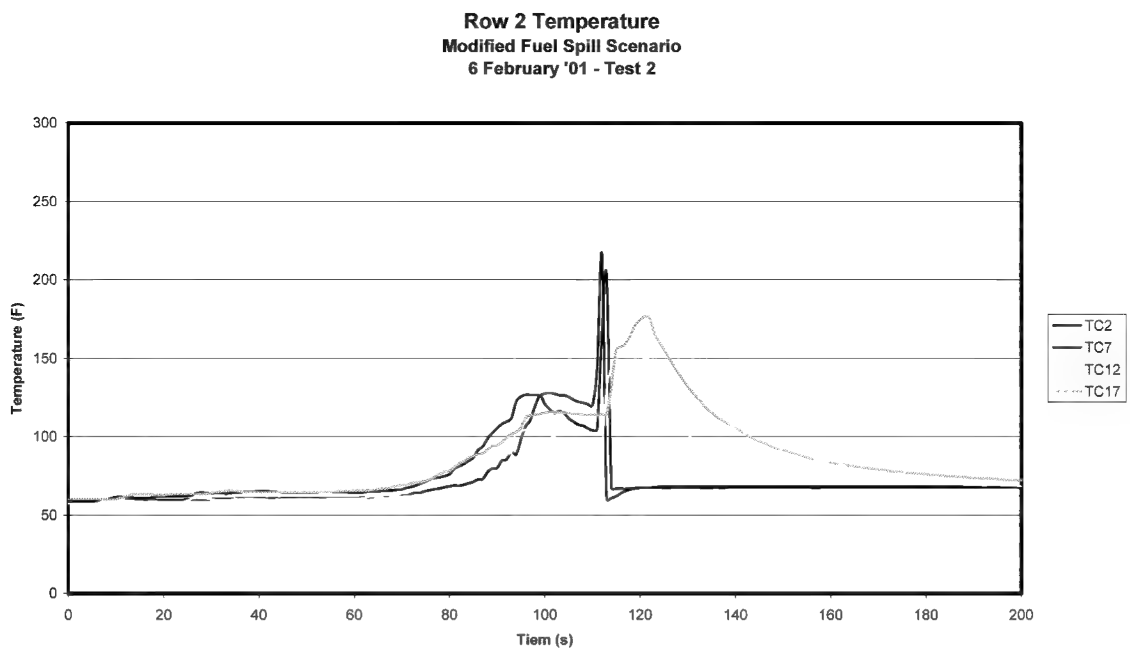


Figure A-18: Test 2 Row 2 Ceiling Temperatures

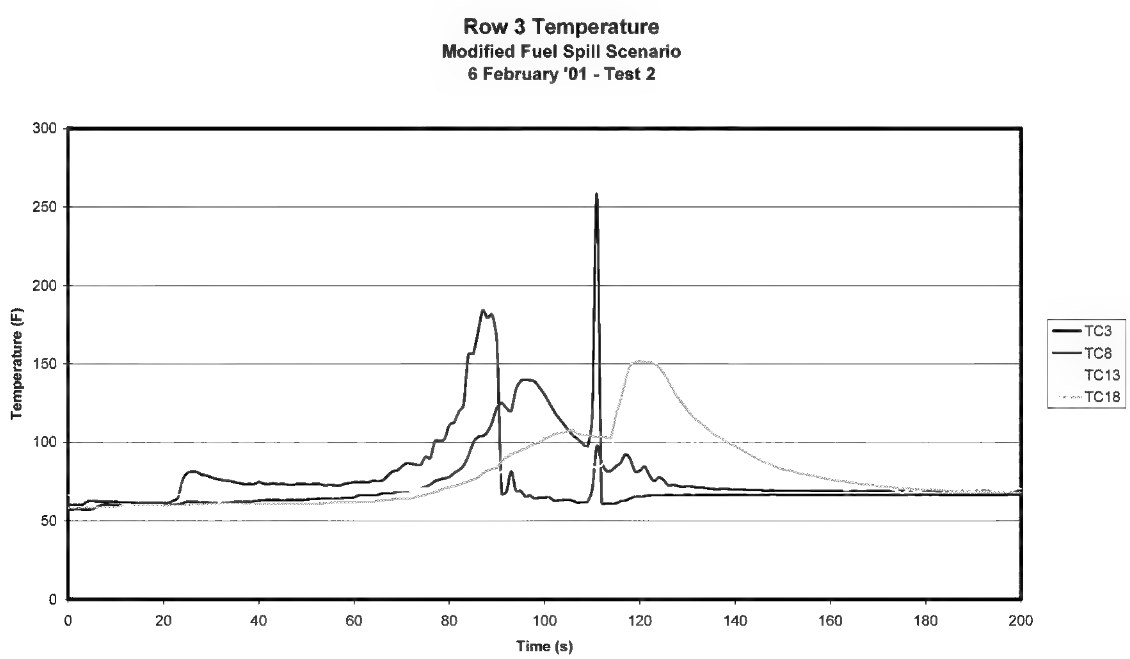


Figure A-19: Test 2 Row 3 Ceiling Temperatures

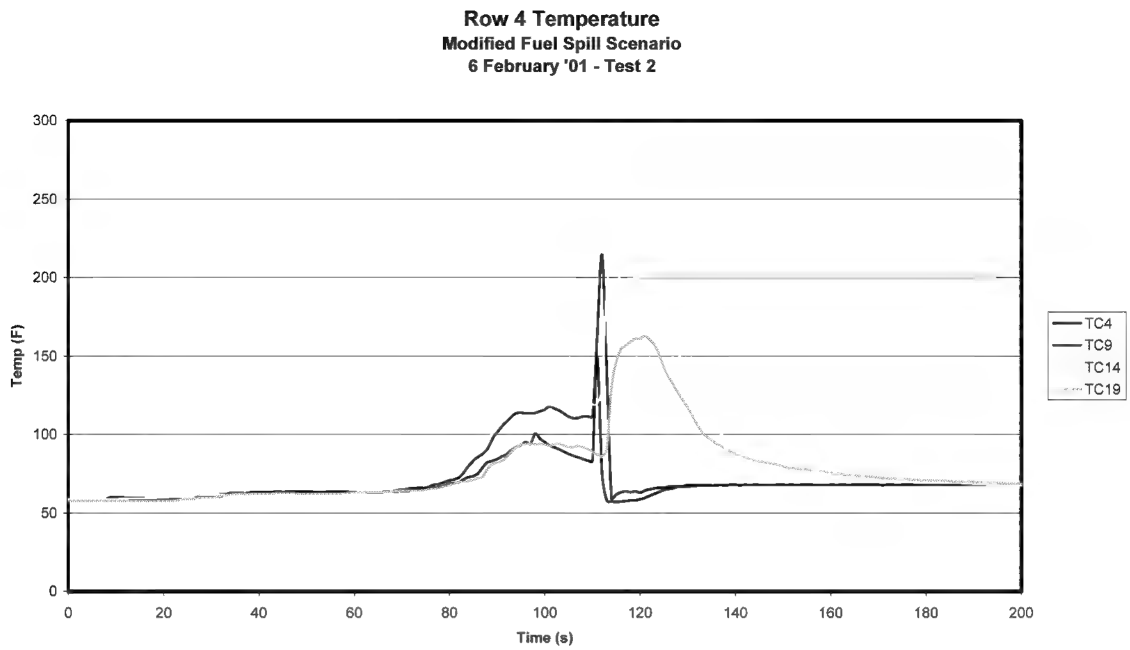


Figure A-20: Test 2 Row 4 Ceiling Temperatures

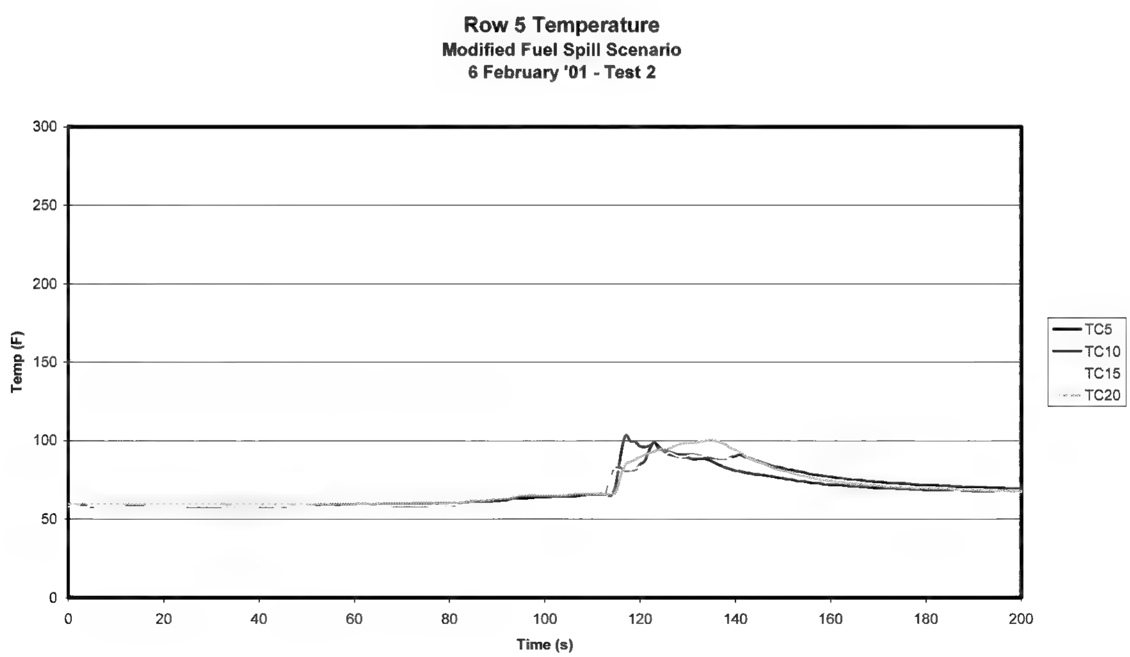
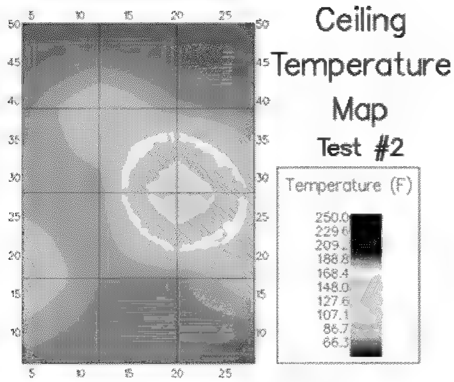
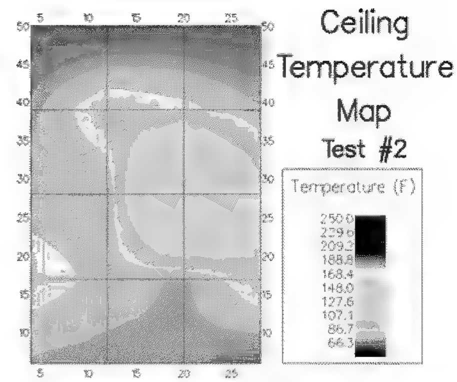


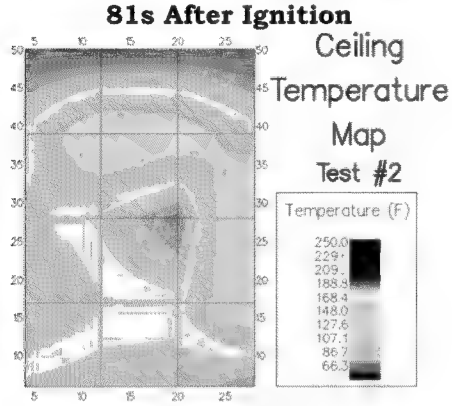
Figure A-21: Test 2 Row 5 Ceiling Temperatures



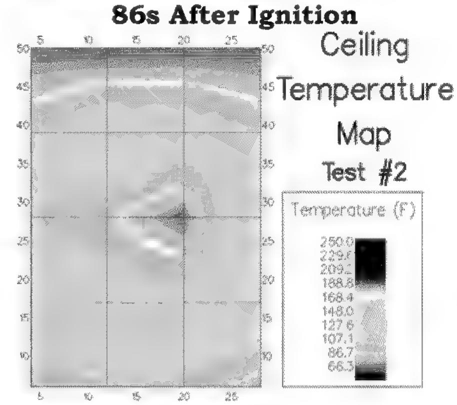
81s After Ignition



86s After Ignition



91s After Ignition



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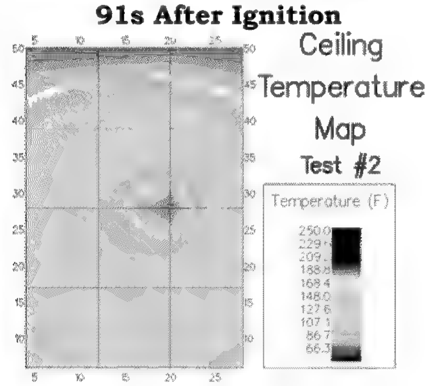

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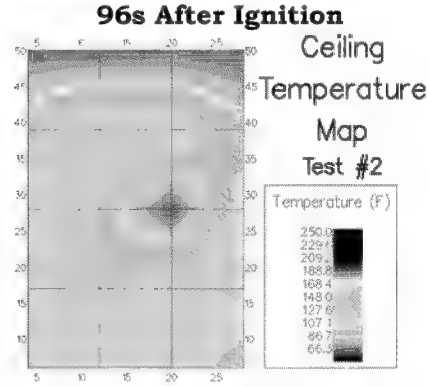

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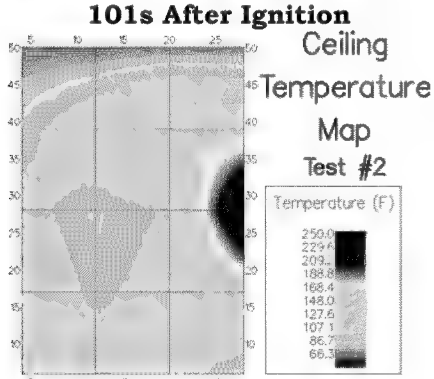
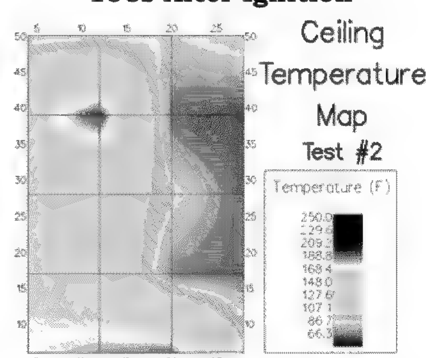


111s After Ignition



116s After Ignition

Figure A-22: Test 2 Ceiling Temperatures @ 5 Second Intervals

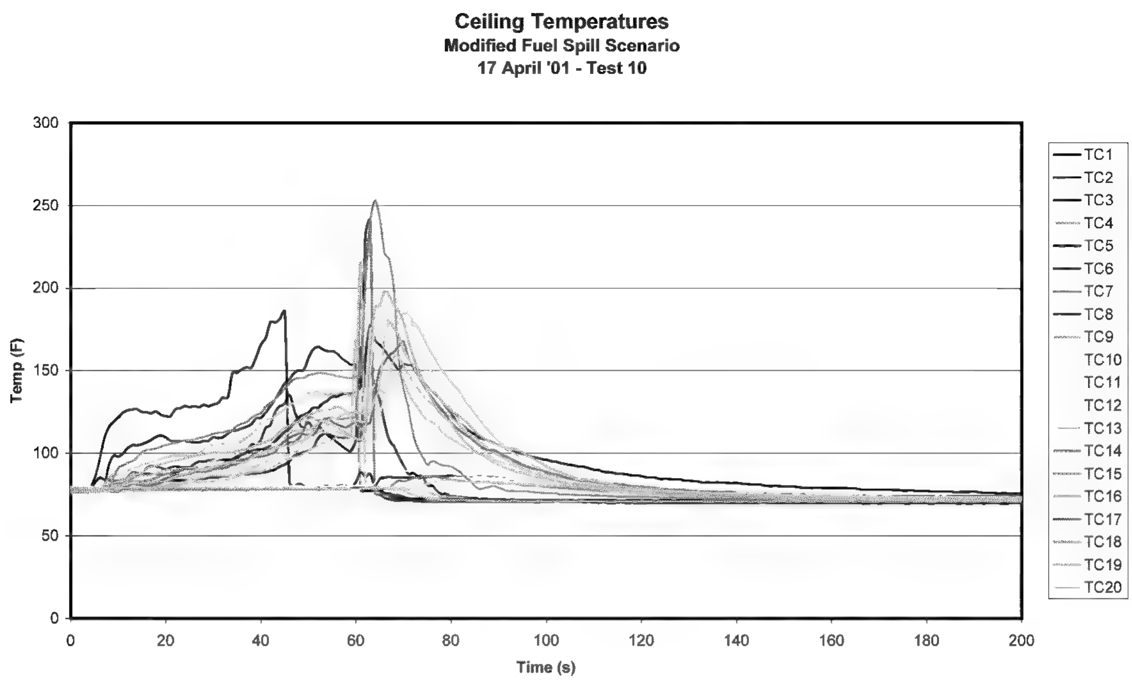


Figure A-23: Test 10 All Ceiling Temperatures

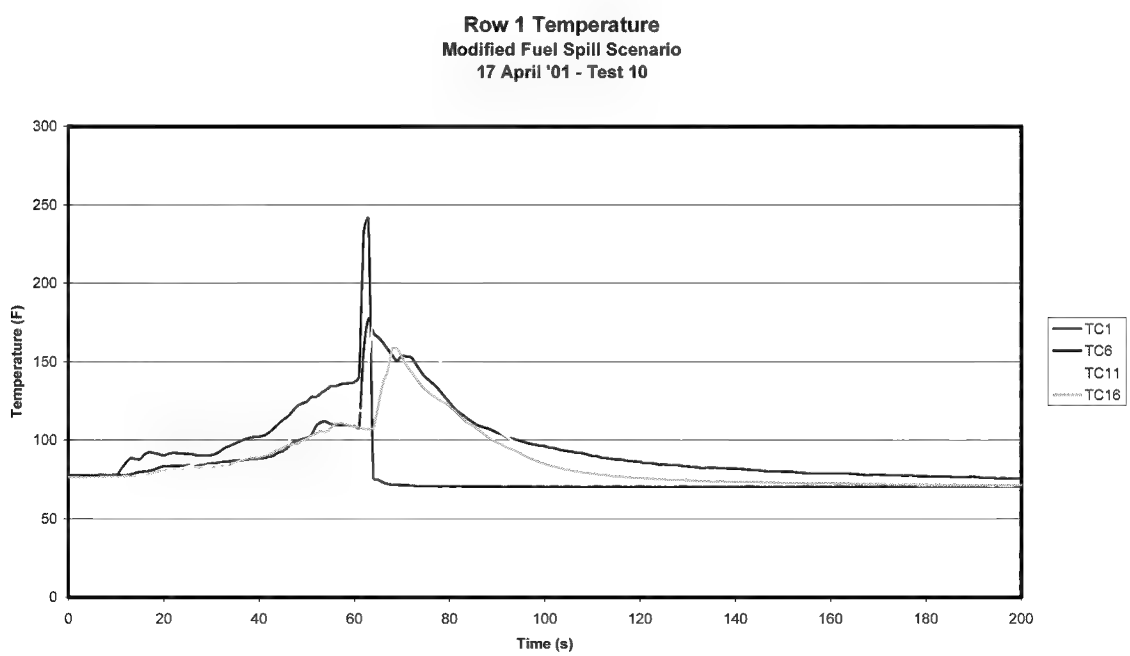


Figure A-24: Test 10 Row 1 Ceiling Temperatures

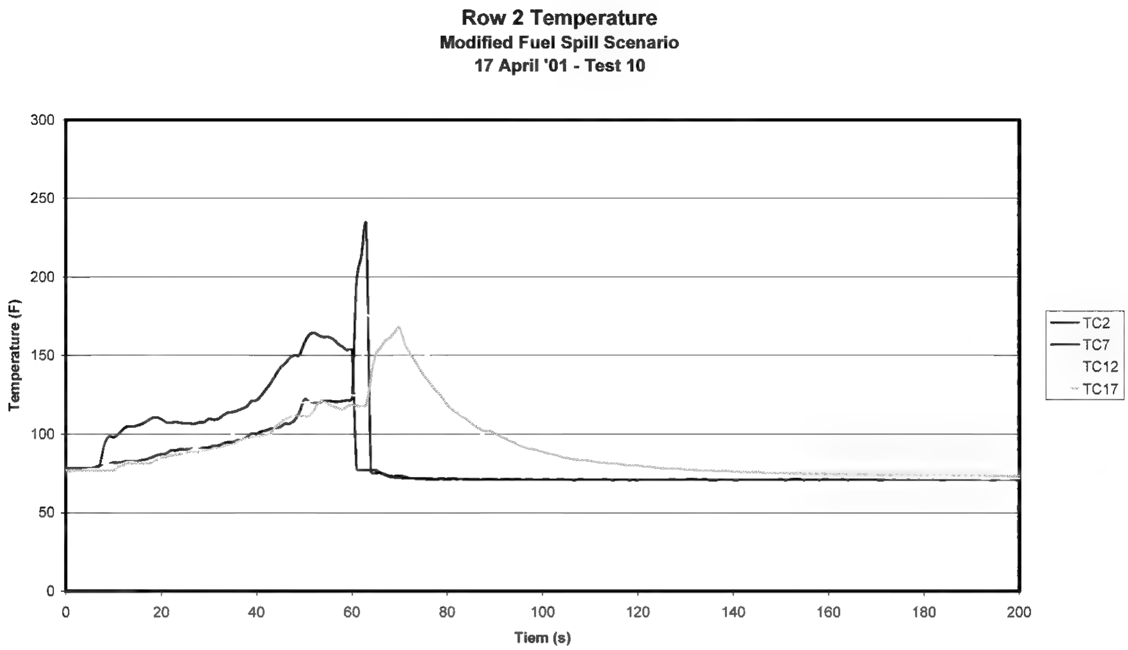


Figure A-25: Test 10 Row 2 Ceiling Temperatures

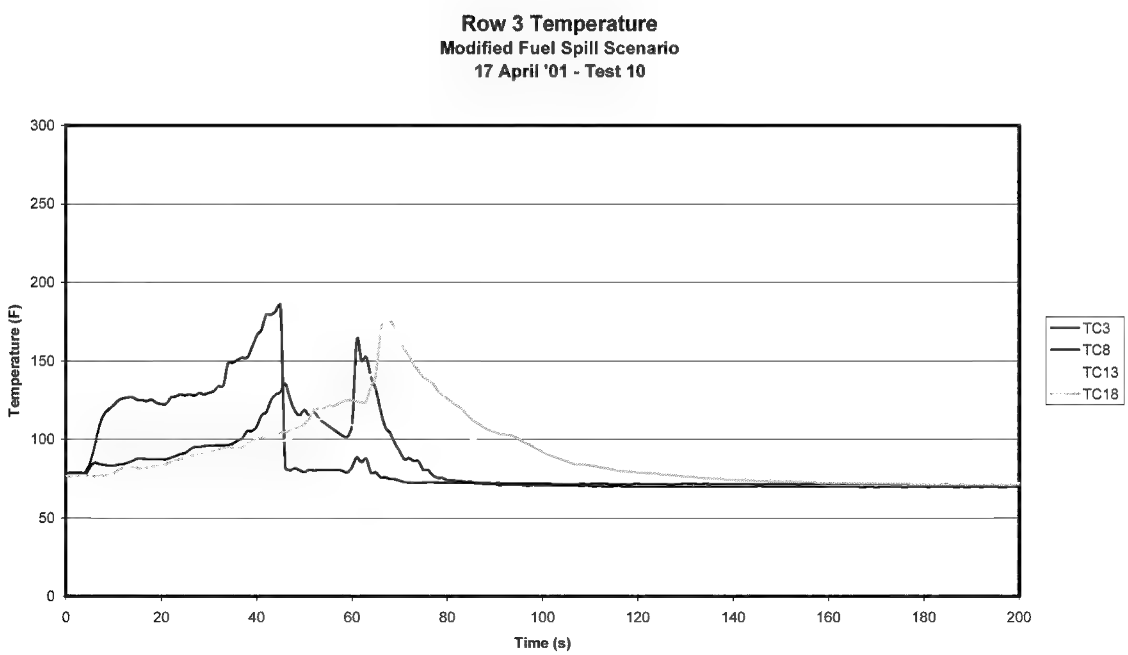


Figure A-26: Test 10 Row 3 Ceiling Temperatures

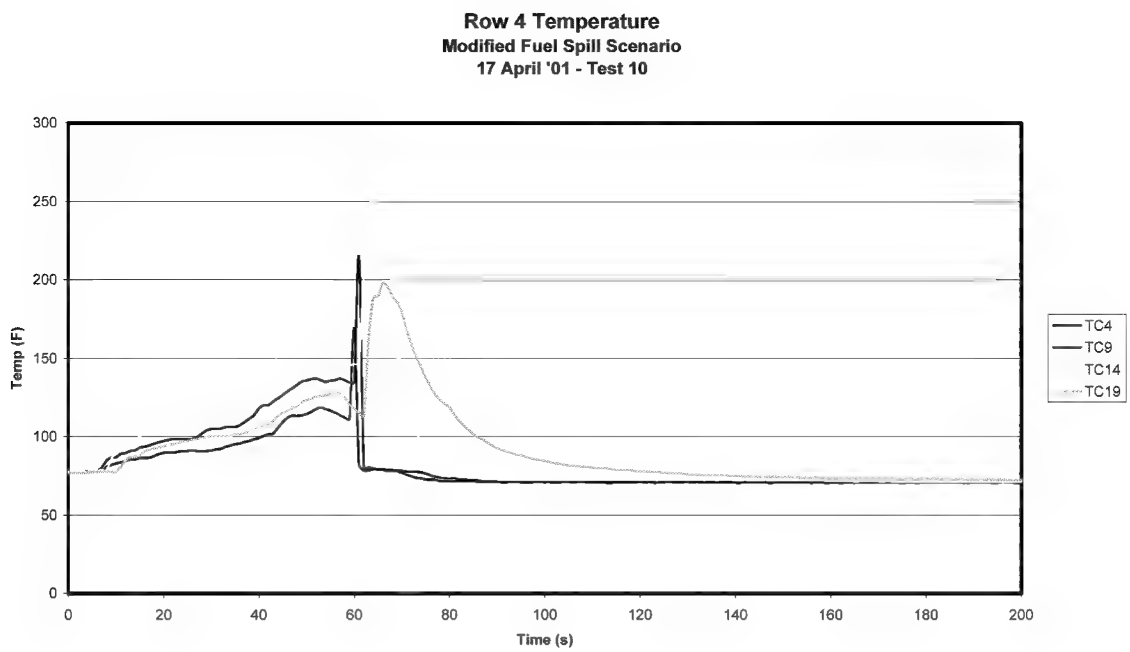


Figure A-27: Test 10 Row 4 Ceiling Temperatures

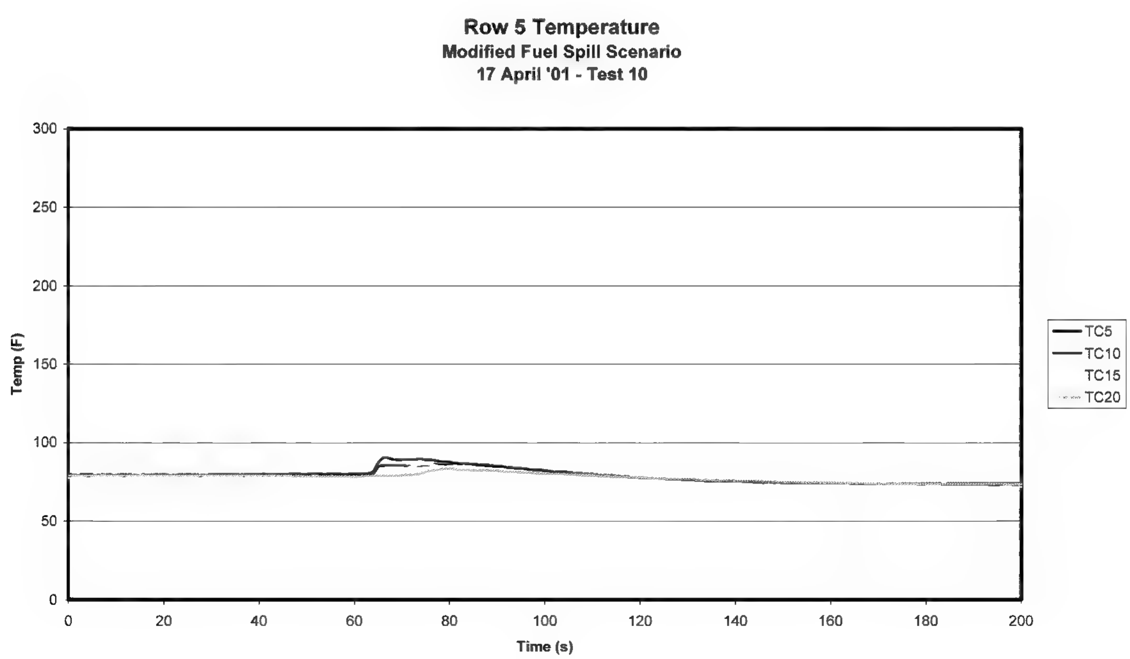
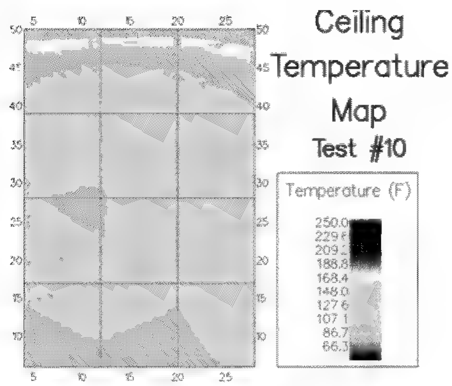
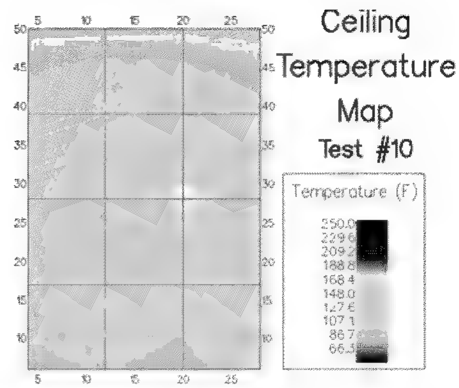


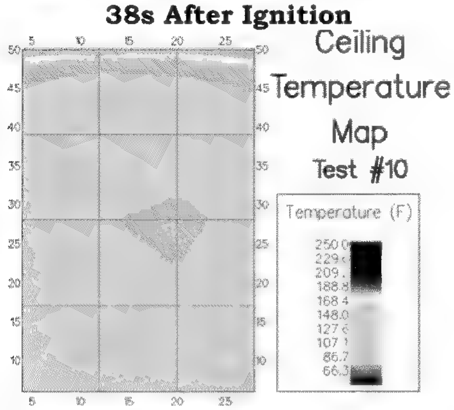
Figure A-28: Test 10 Row 5 Ceiling Temperatures



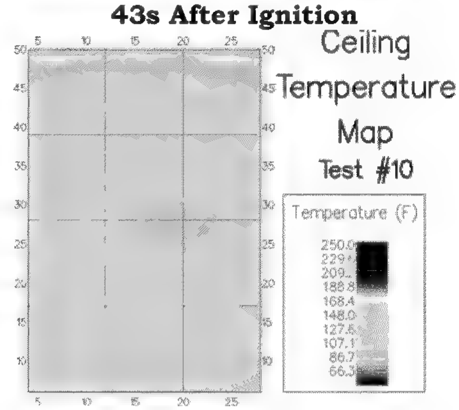
38s After Ignition



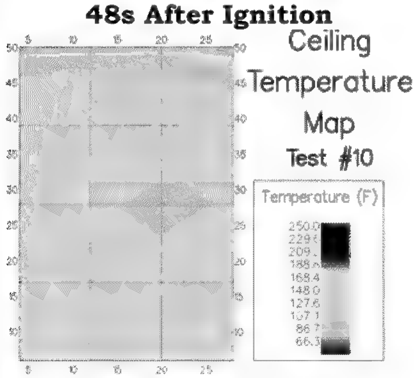
43s After Ignition



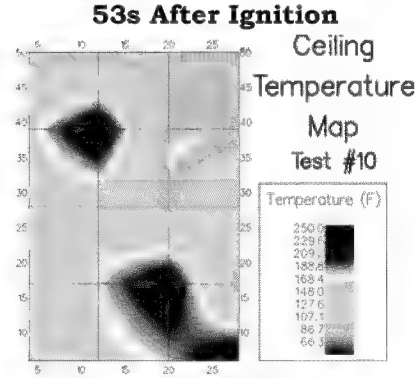
48s After Ignition



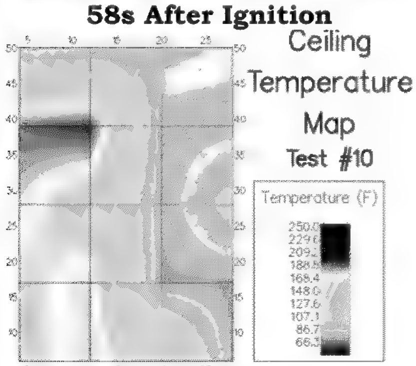
53s After Ignition



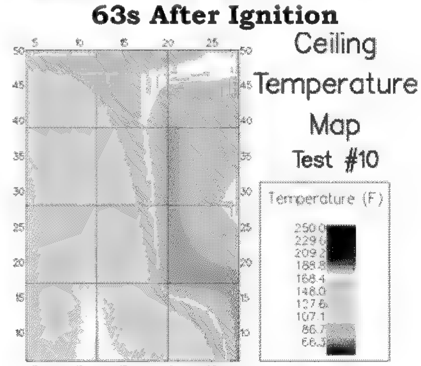
58s After Ignition



63s After Ignition



68s After Ignition



73s After Ignition

Figure A-29: Test 10 Ceiling Temperatures @ 5 Second Intervals

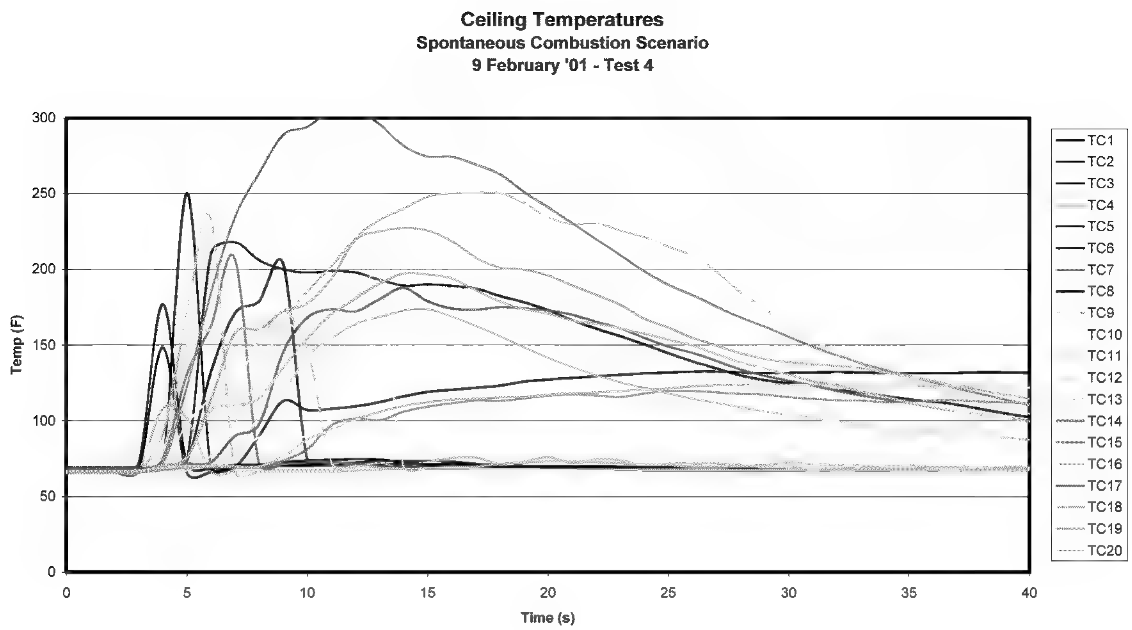


Figure A-30: Test 4 All Ceiling Temperatures

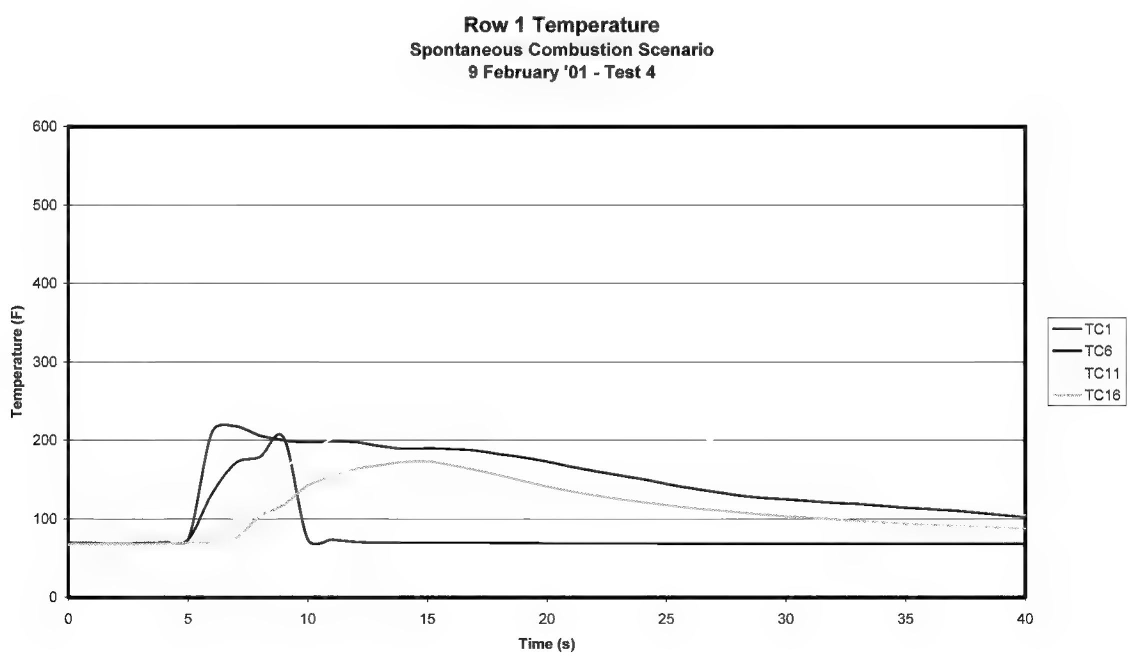


Figure A-31: Test 4 Row 1 Ceiling Temperatures

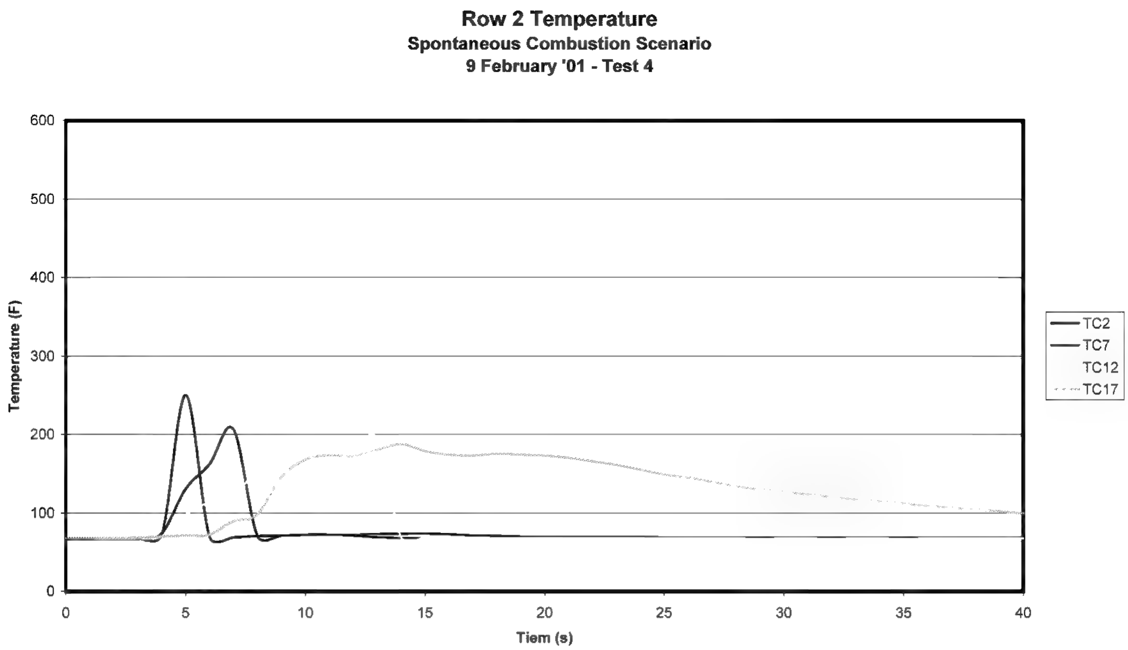


Figure A-32: Test 4 Row 2 Ceiling Temperatures

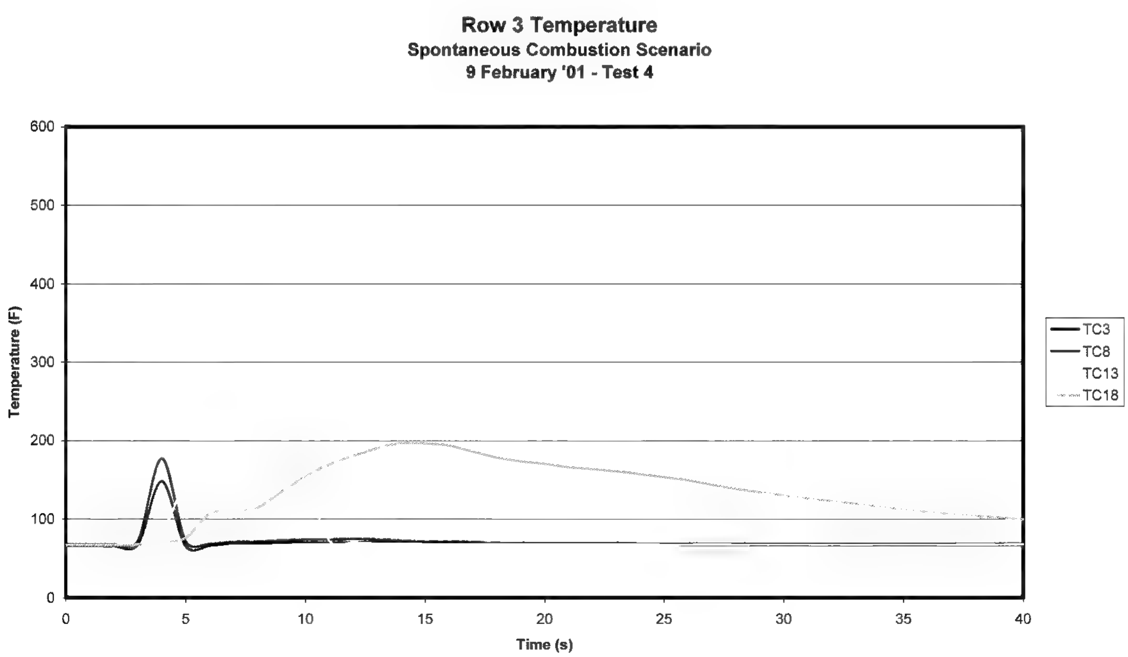


Figure A-33: Test 4 Row 3 Ceiling Temperatures

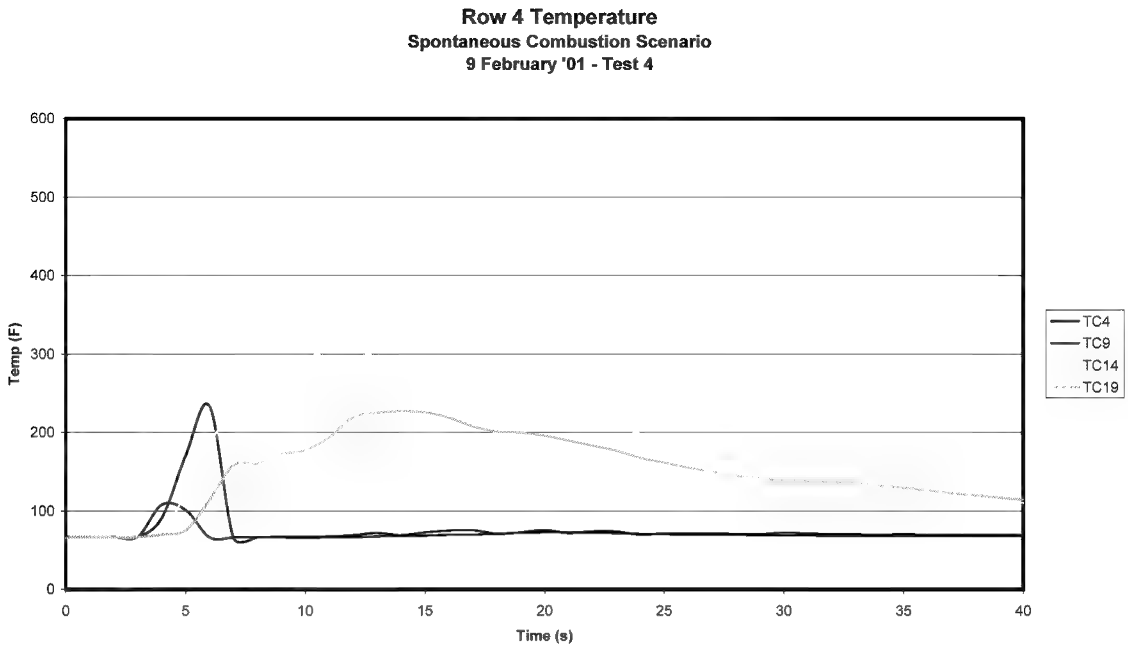


Figure A-34: Test 4 Row 4 Ceiling Temperatures

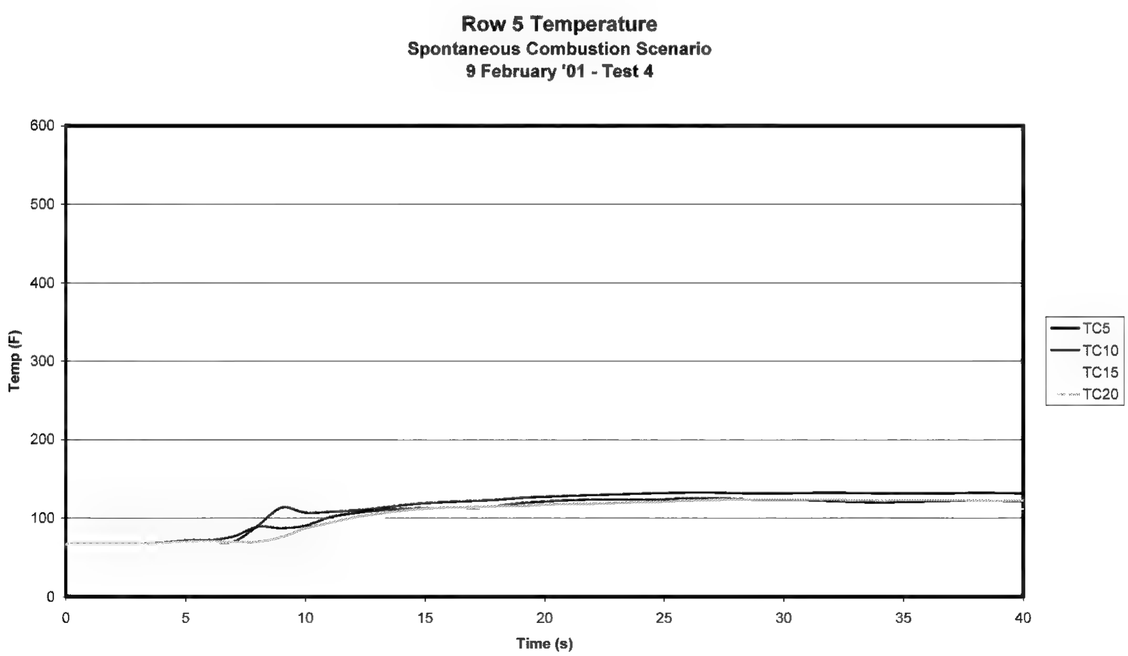


Figure A-35: Test 4 Row 5 Ceiling Temperatures

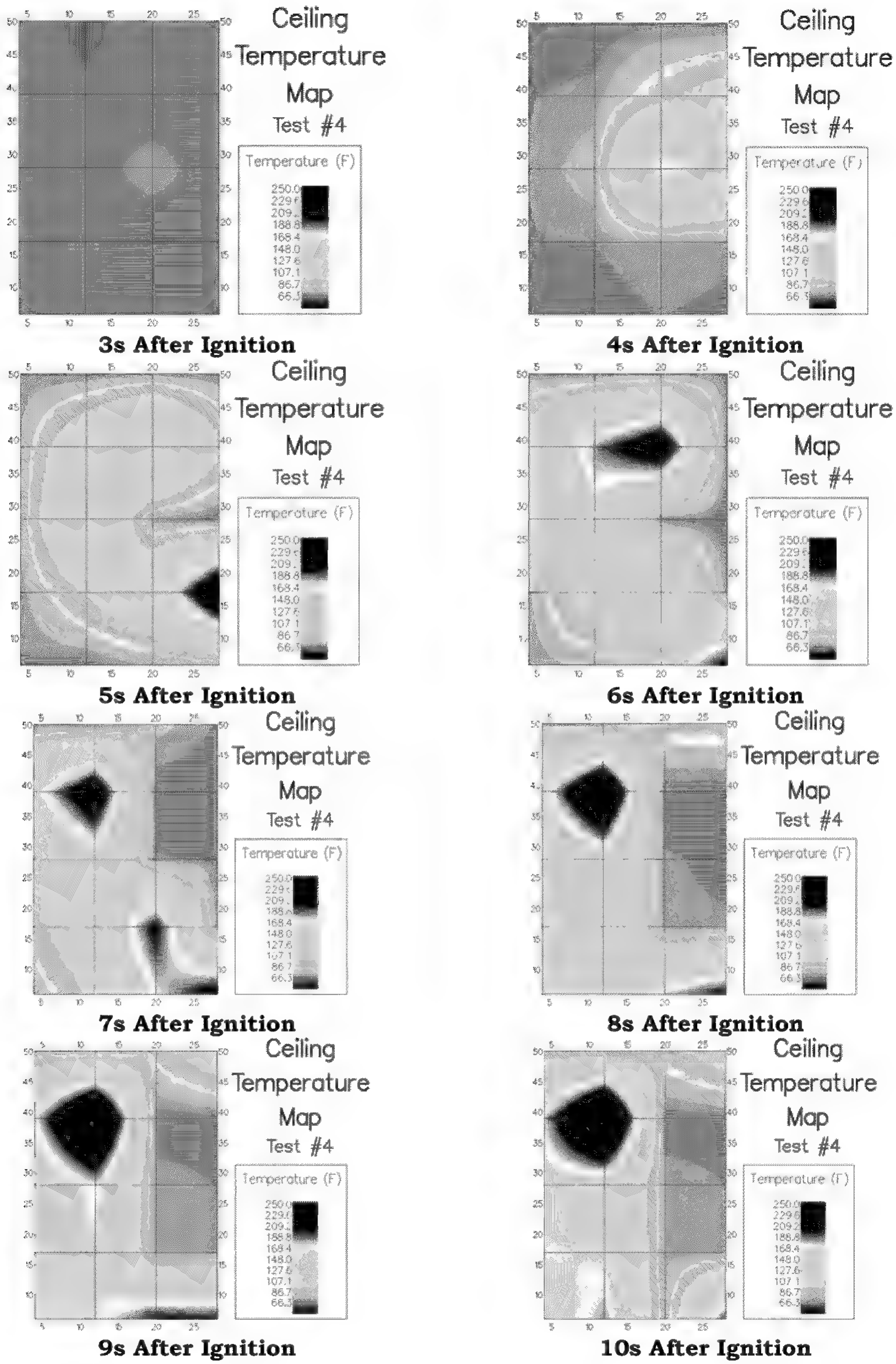


Figure A-36: Test 4 Ceiling Temperatures @ 1 Second Intervals

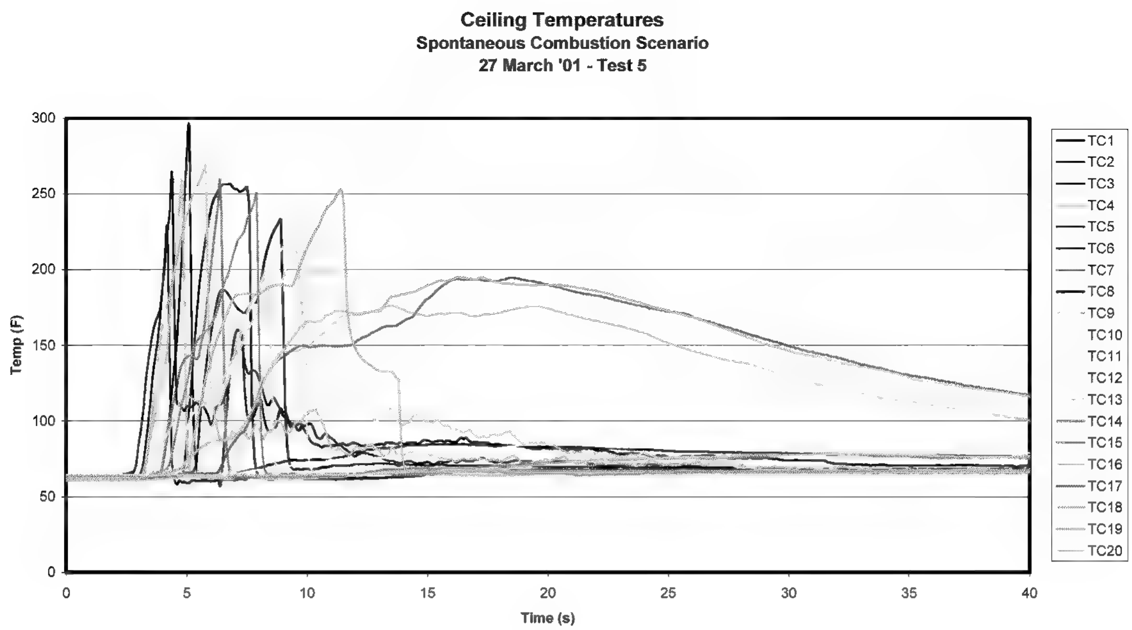


Figure A-37: Test 5 All Ceiling Temperatures

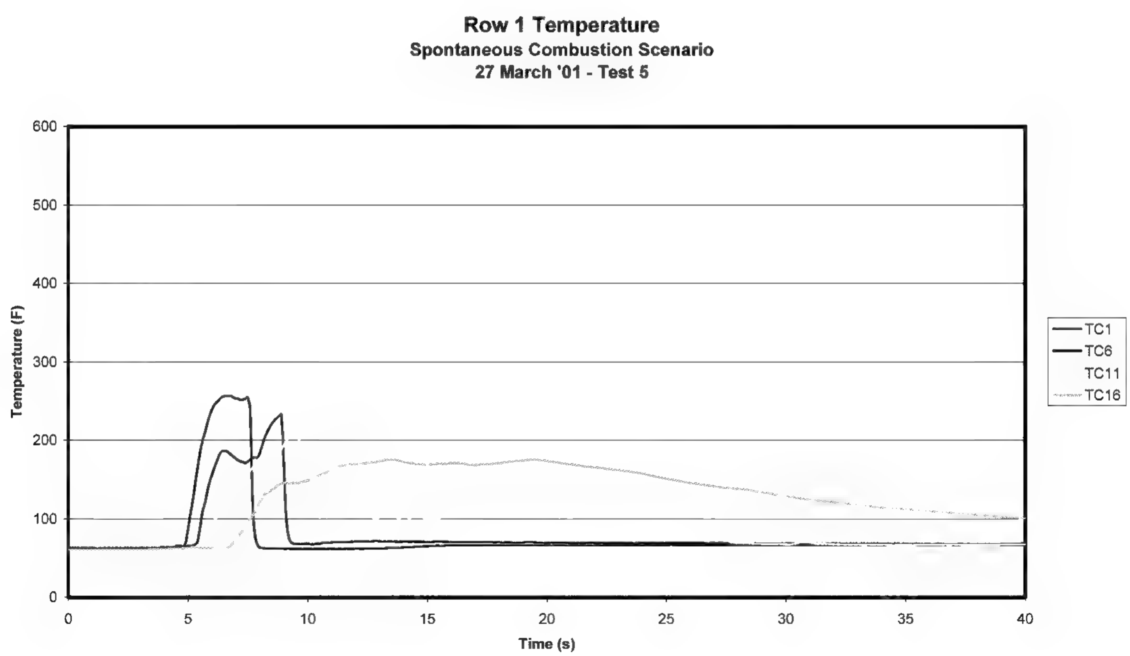


Figure A-38: Test 5 Row 1 Ceiling Temperatures

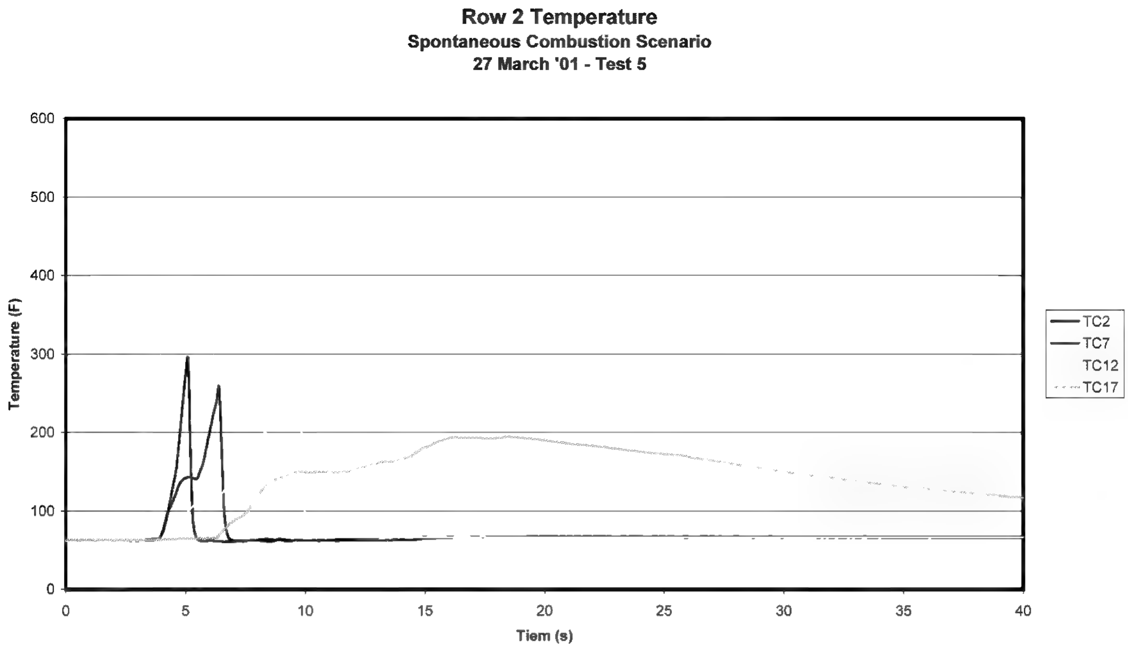


Figure A-39: Test 5 Row 2 Ceiling Temperatures

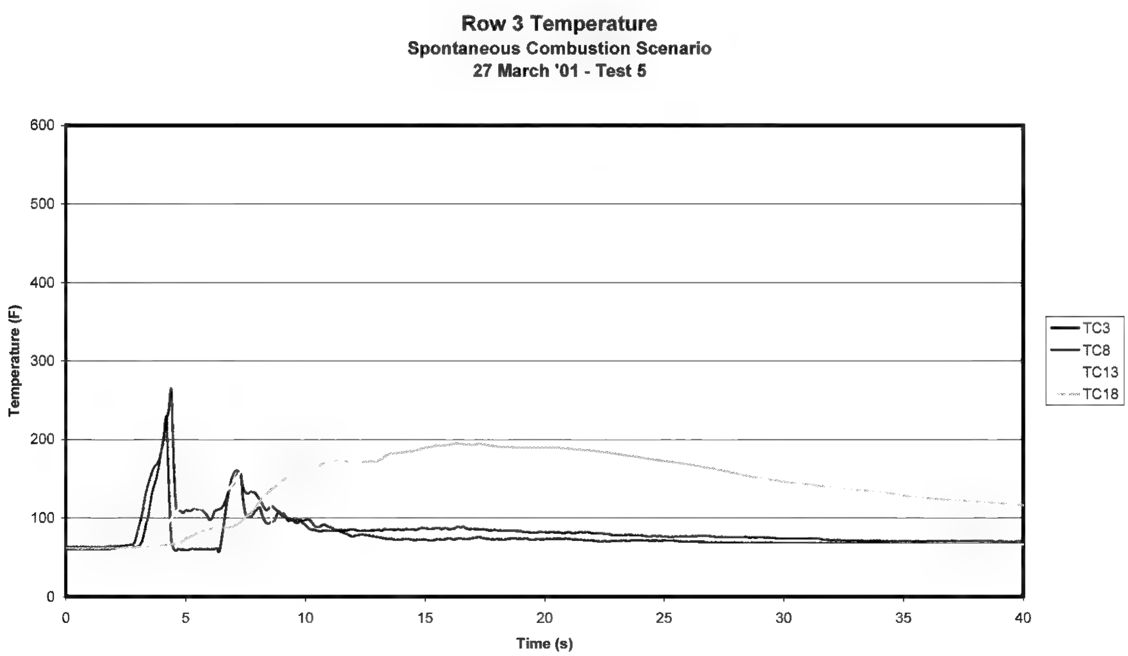


Figure A-40: Test 5 Row 3 Ceiling Temperatures

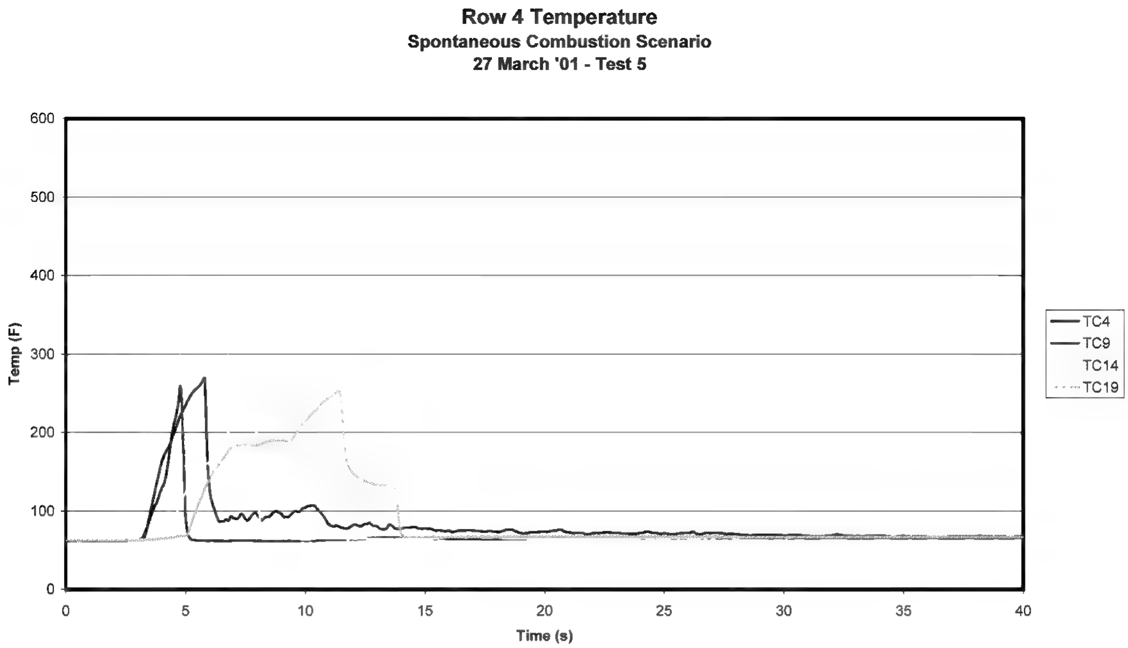


Figure A-41: Test 5 Row 4 Ceiling Temperatures

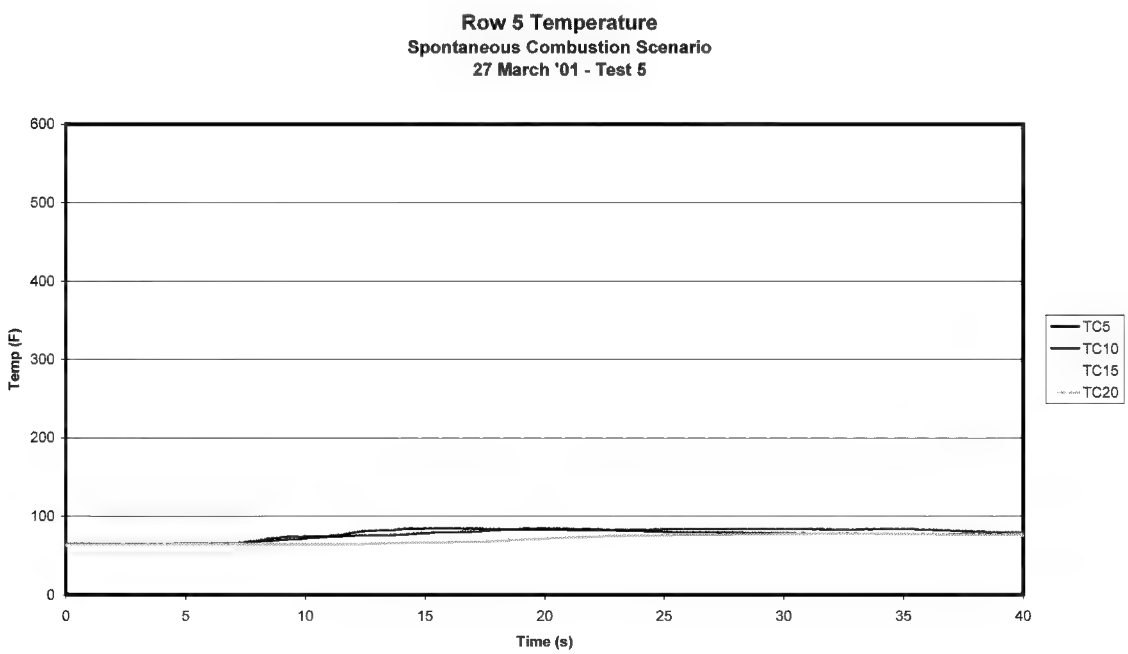


Figure A-42: Test 5 Row 5 Ceiling Temperatures

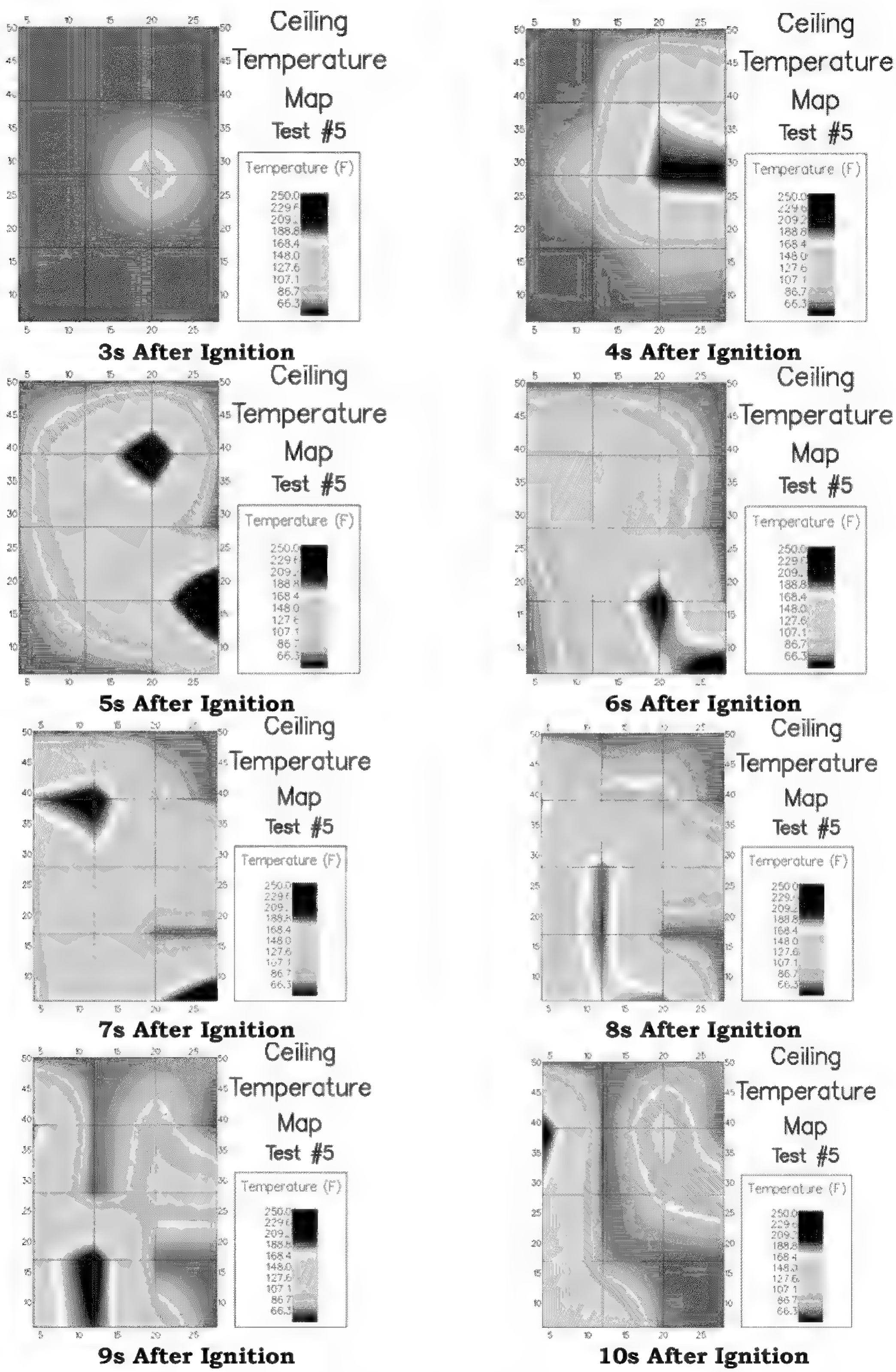


Figure A-43: Test 5 Ceiling Temperatures @ 1 Second Intervals

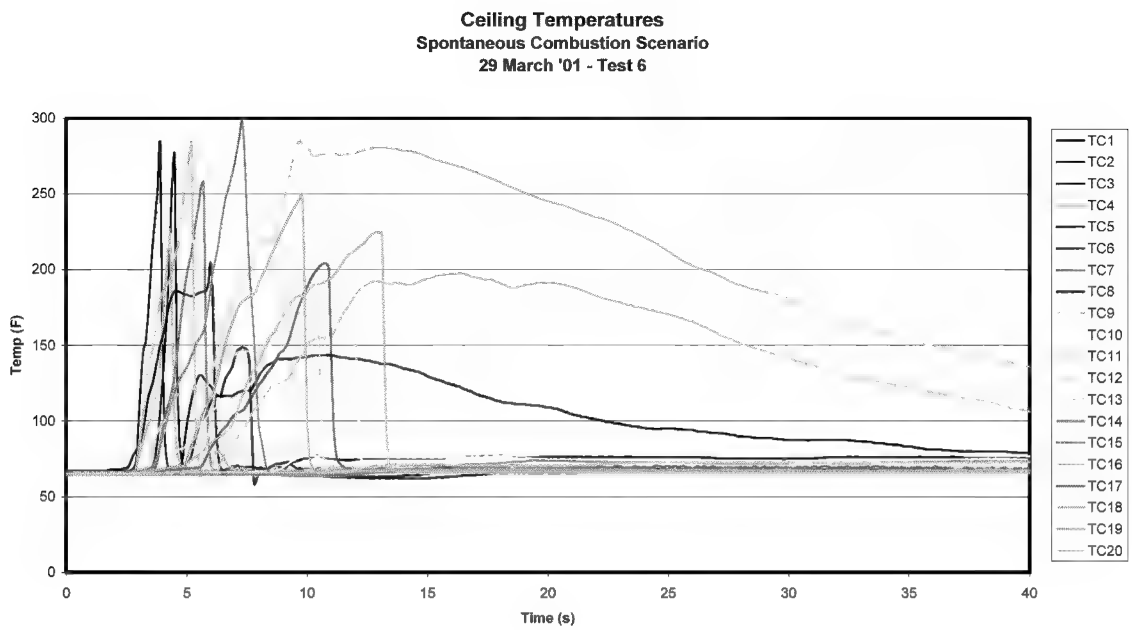


Figure A-44: Test 6 All Ceiling Temperatures

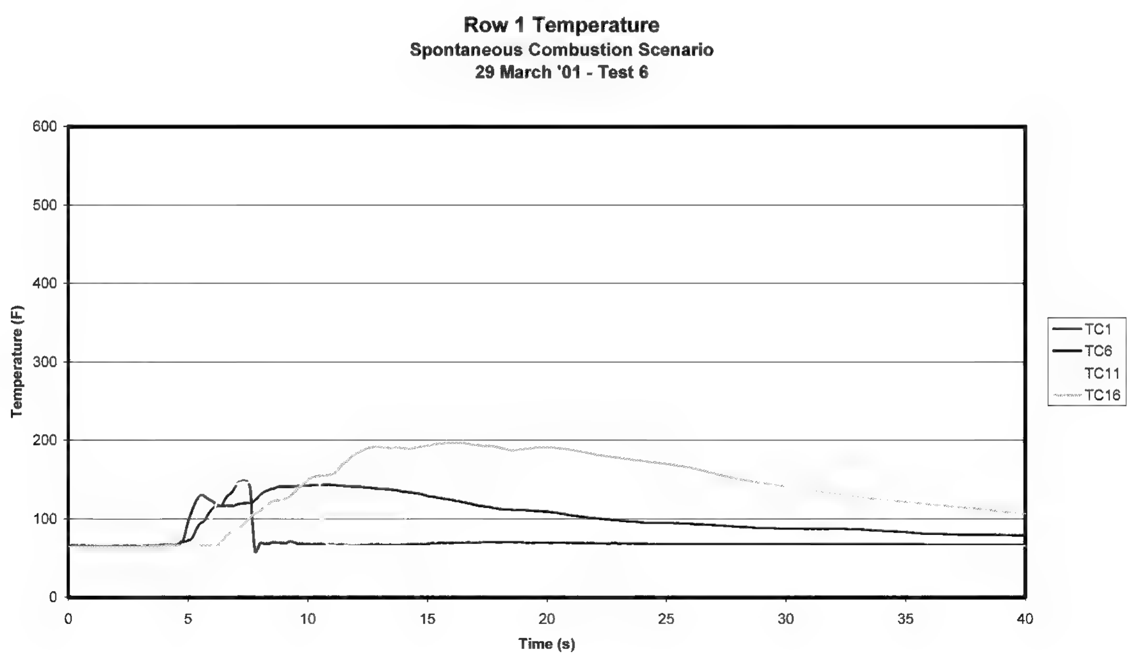


Figure A-45: Test 6 Row 1 Ceiling Temperatures

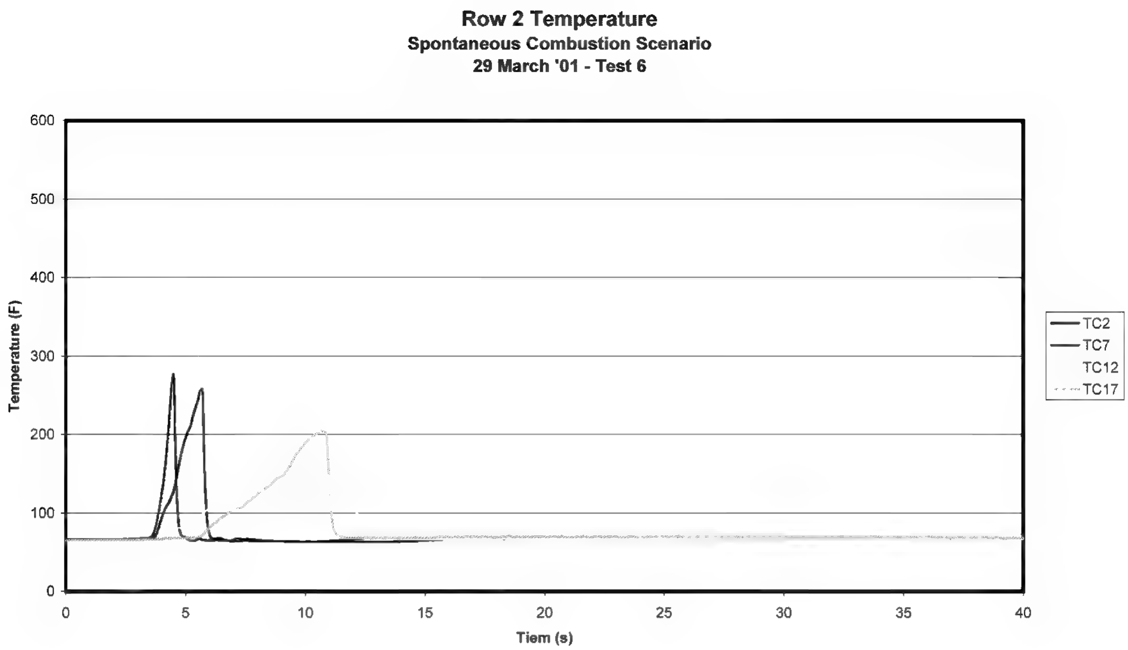


Figure A-46: Test 6 Row 2 Ceiling Temperatures

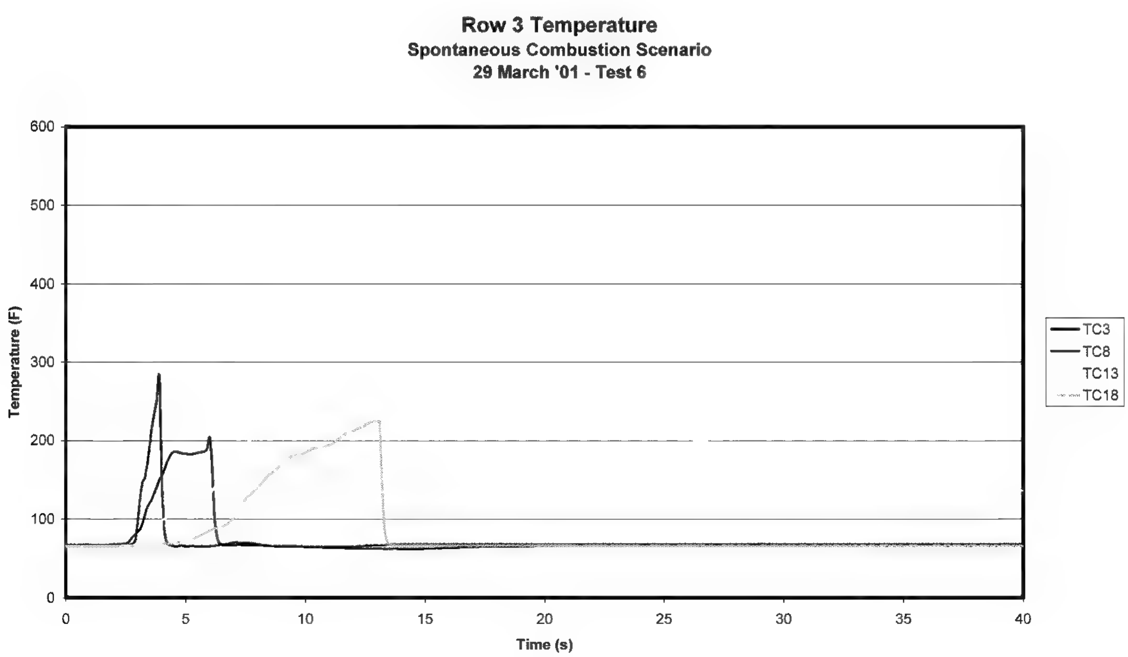


Figure A-47: Test 6 Row 3 Ceiling Temperatures

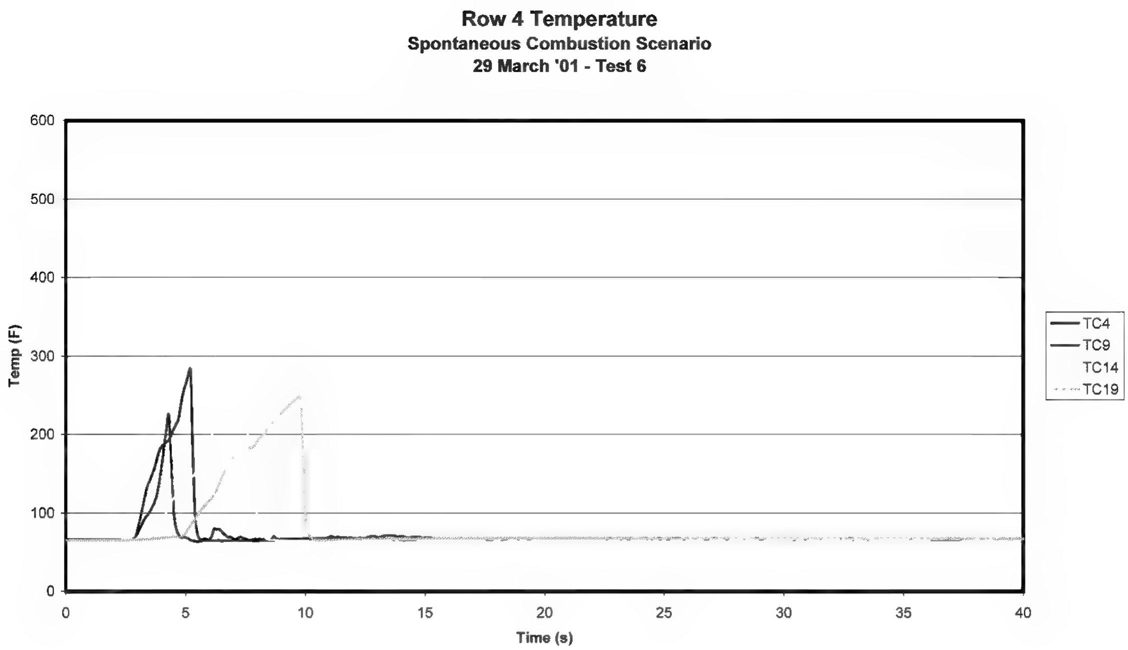


Figure A-48: Test 6 Row 4 Ceiling Temperatures

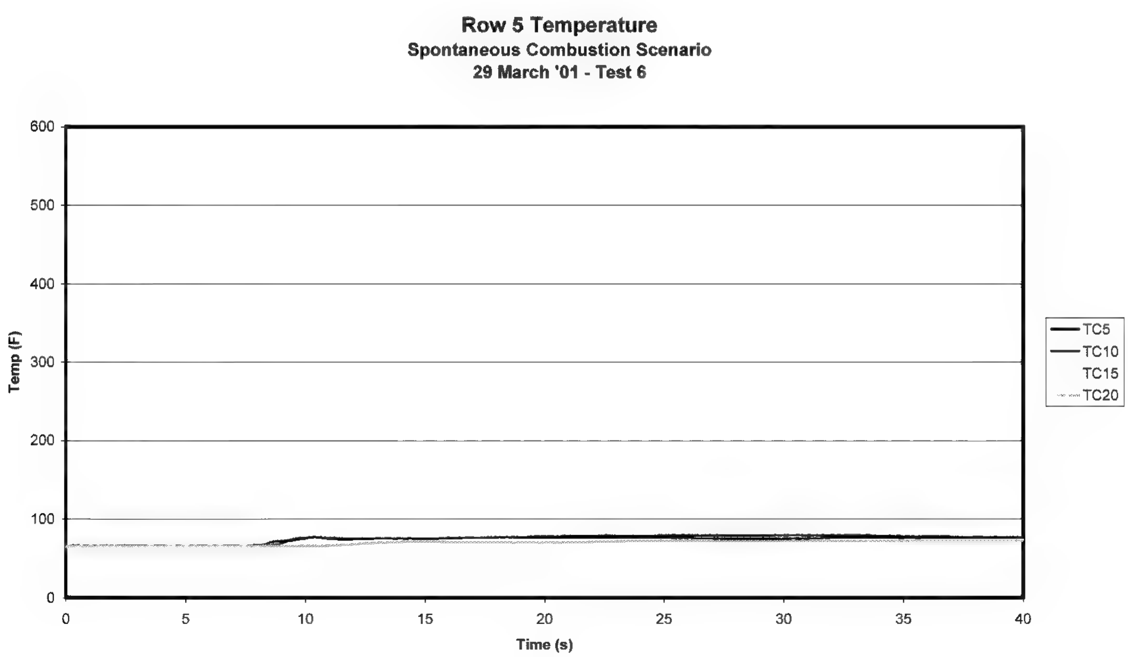
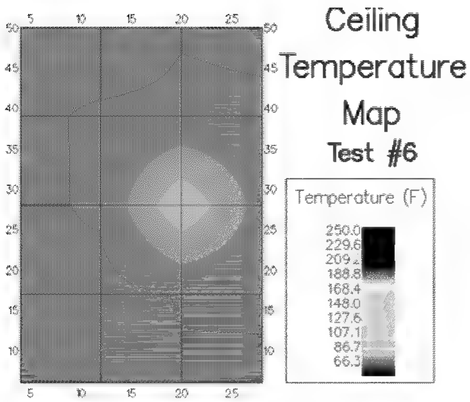
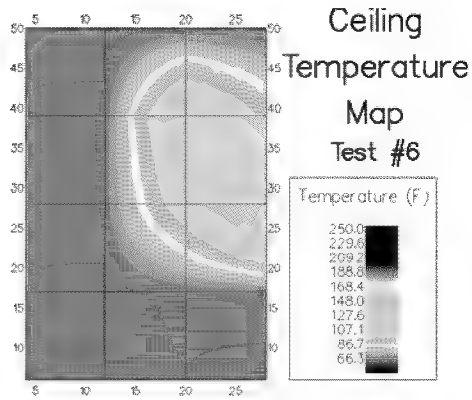


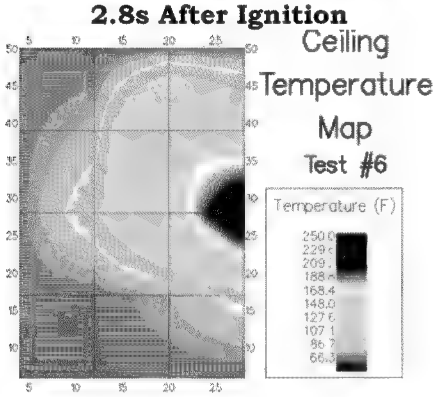
Figure A-49: Test 6 Row 5 Ceiling Temperatures



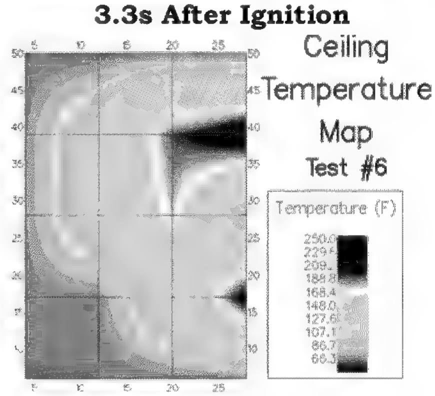
2.8s After Ignition



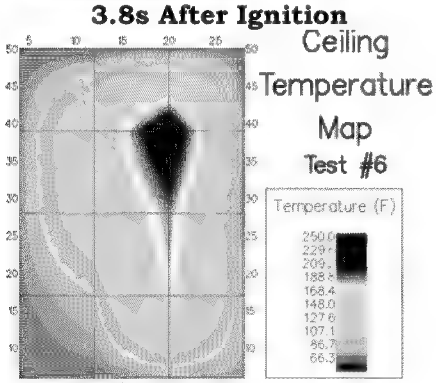
3.3s After Ignition



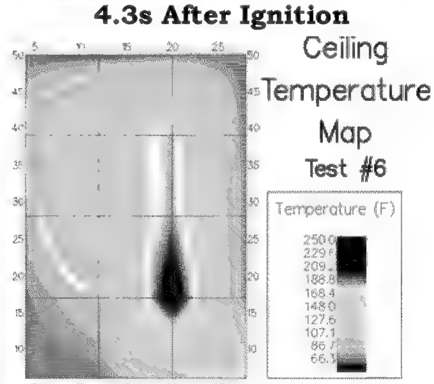
3.8s After Ignition



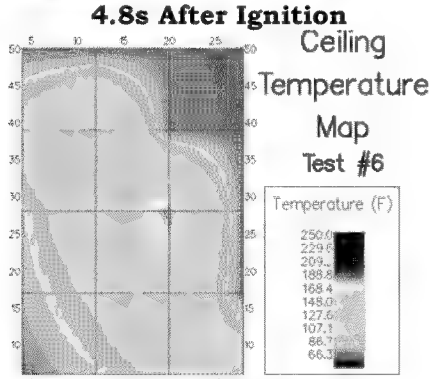
4.3s After Ignition



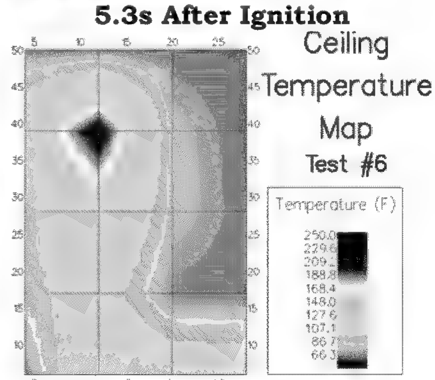
4.8s After Ignition



5.3s After Ignition



5.8s After Ignition



6.3s After Ignition

Figure A-50: Test 6 Ceiling Temperatures @ 0.5 Second Intervals

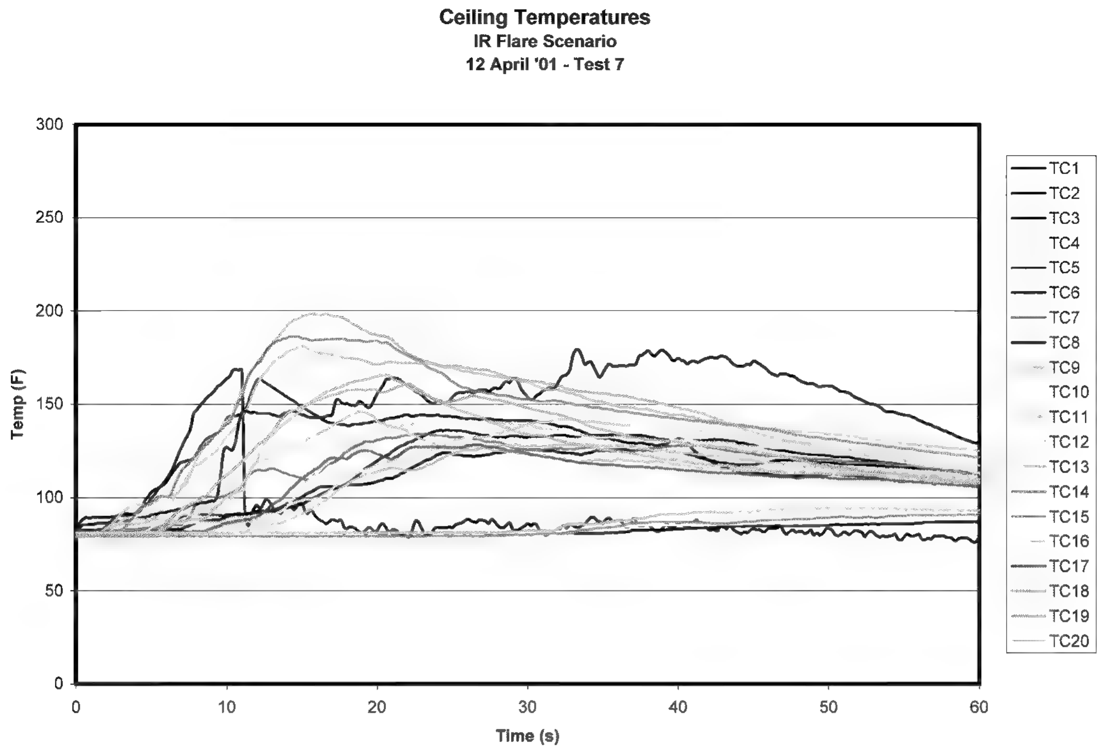


Figure A-51: Test 7 All Ceiling Temperatures

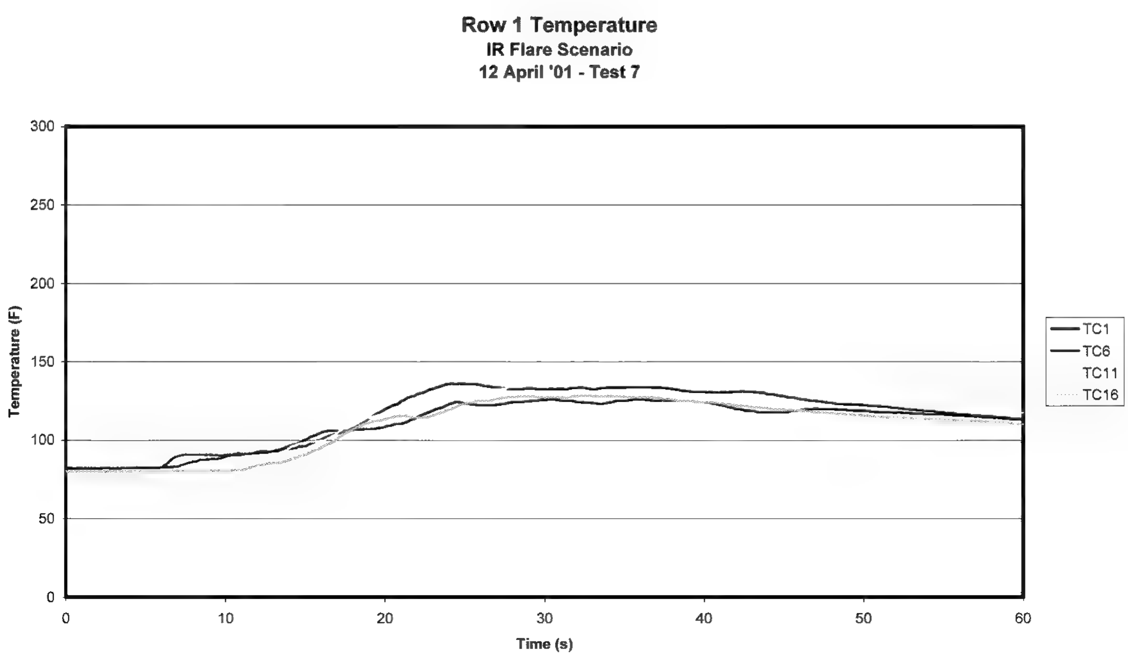


Figure A-52: Test 7 Row 1 Ceiling Temperatures

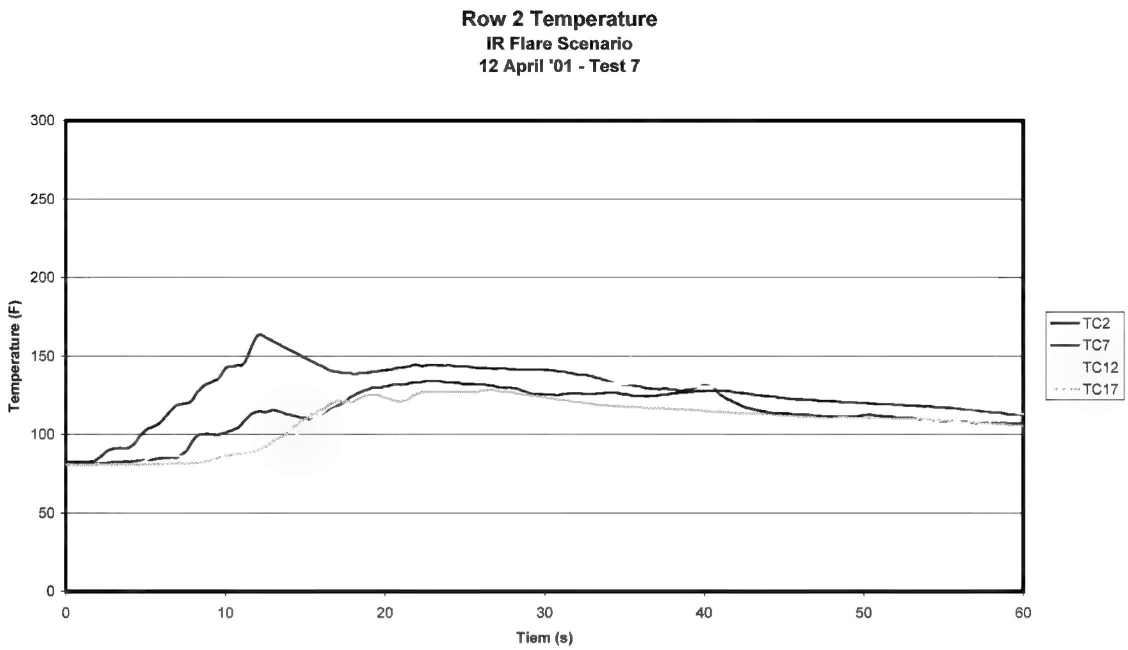


Figure A-53: Test 7 Row 2 Ceiling Temperatures

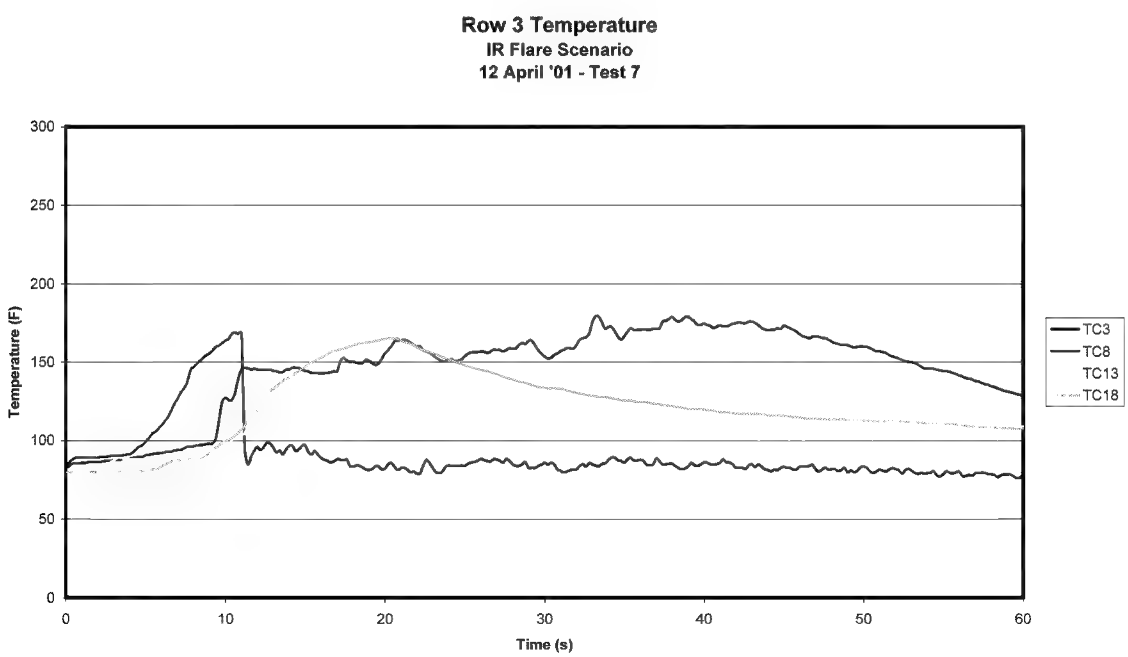


Figure A-54: Test 7 Row 3 Ceiling Temperatures

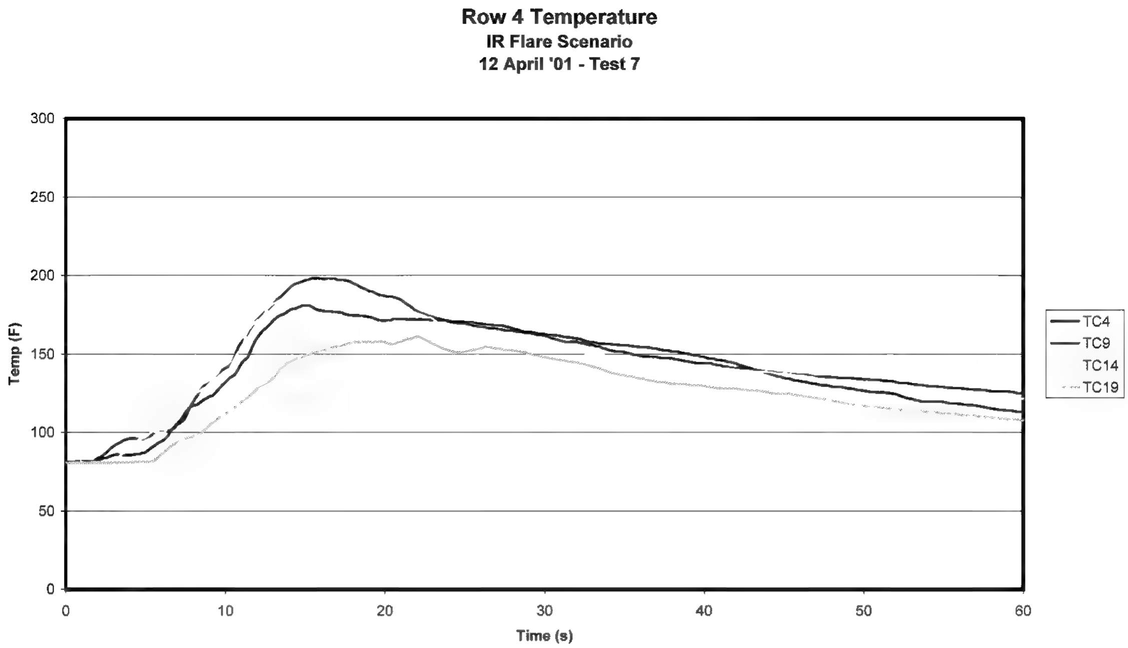


Figure A-55: Test 7 Row 4 Ceiling Temperatures

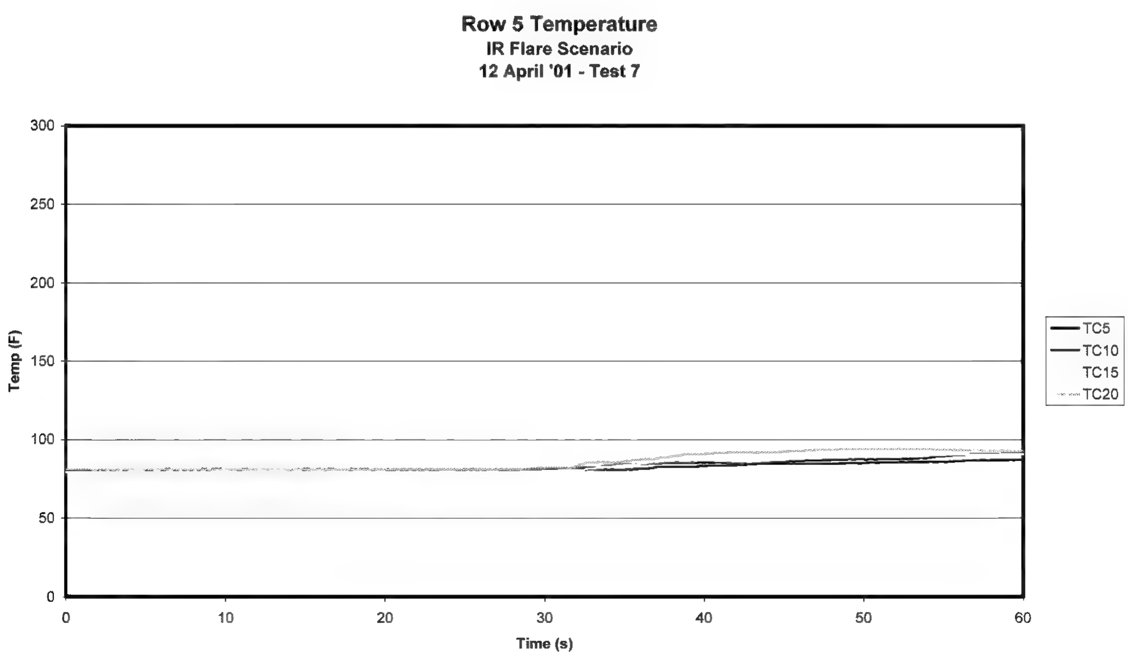
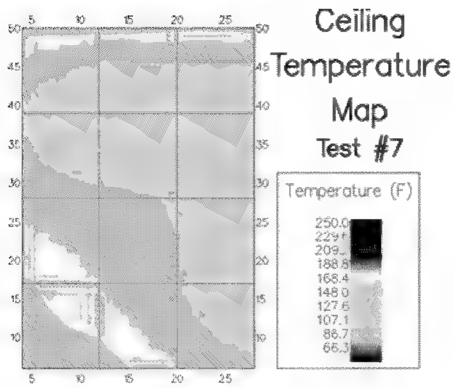
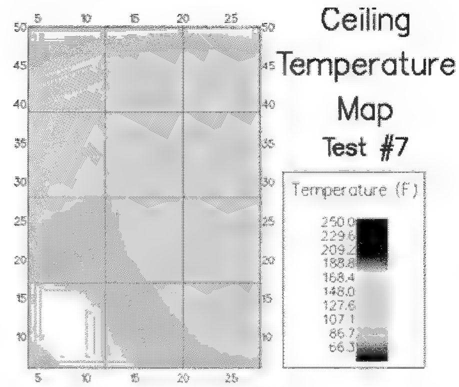


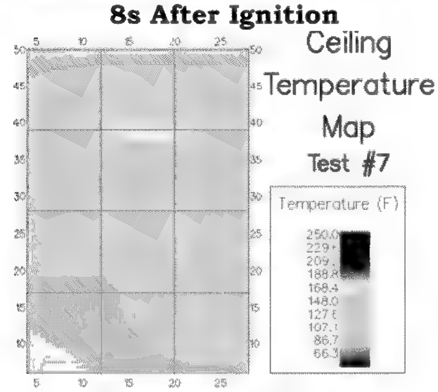
Figure A-56: Test 7 Row 5 Ceiling Temperatures



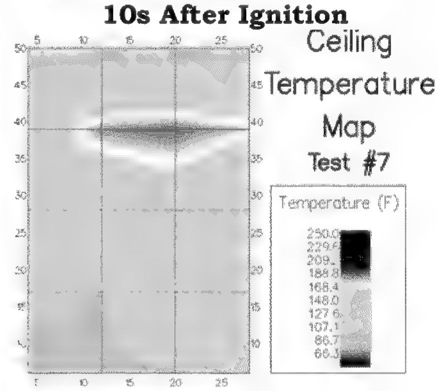
8s After Ignition



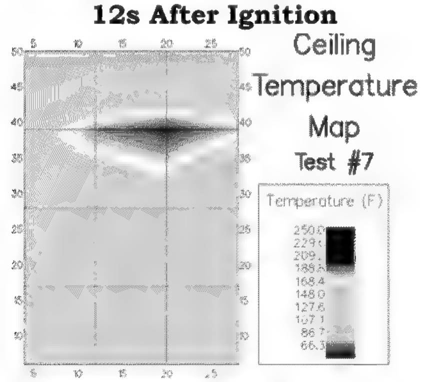
10s After Ignition



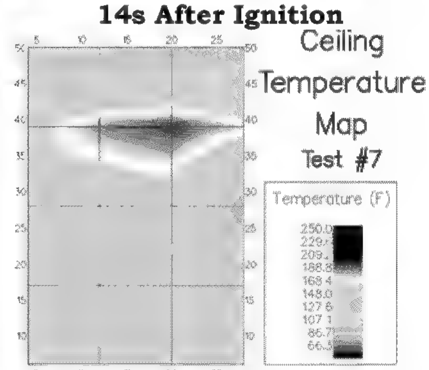
12s After Ignition



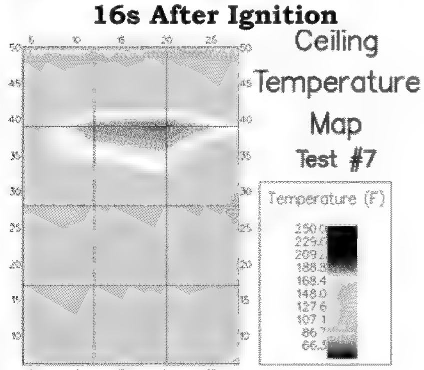
14s After Ignition



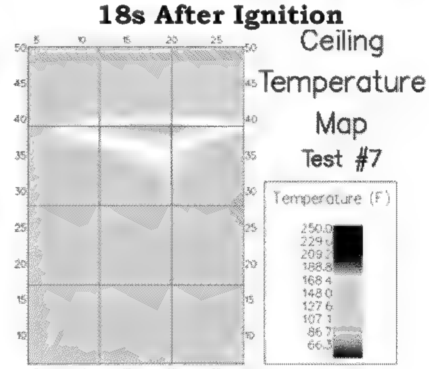
16s After Ignition



18s After Ignition



20s After Ignition



22s After Ignition

Figure A-57: Test 7 Ceiling Temperatures @ 2 Second Intervals

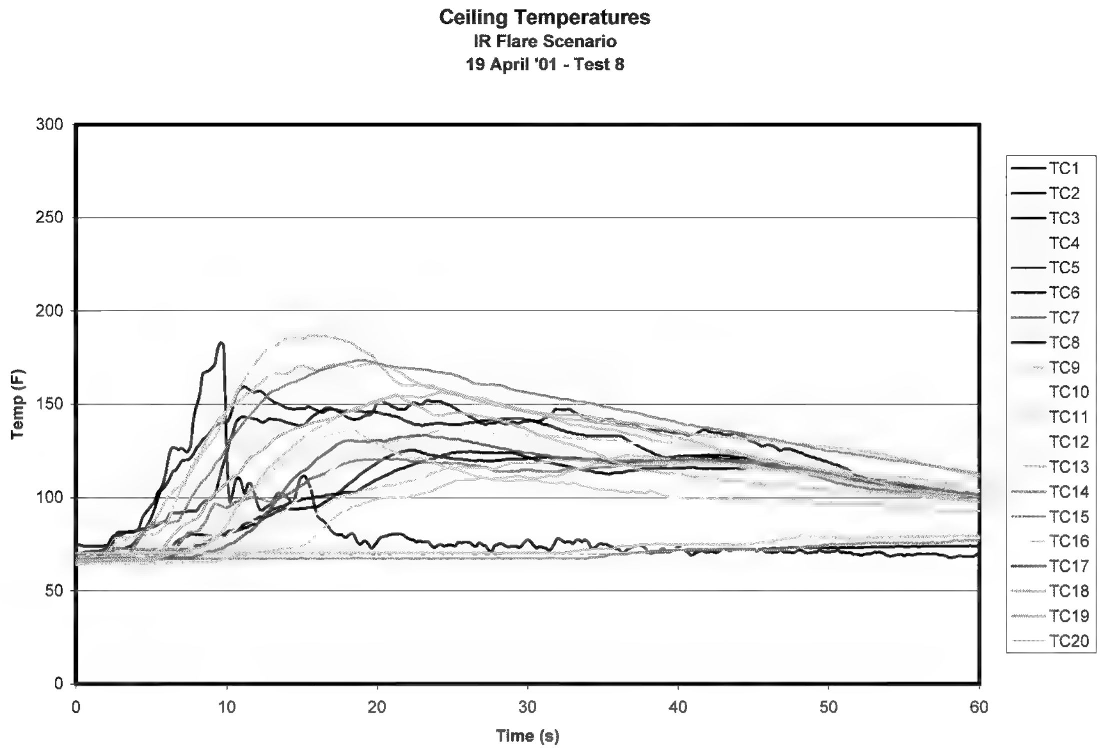


Figure A-58: Test 8 All Ceiling Temperatures

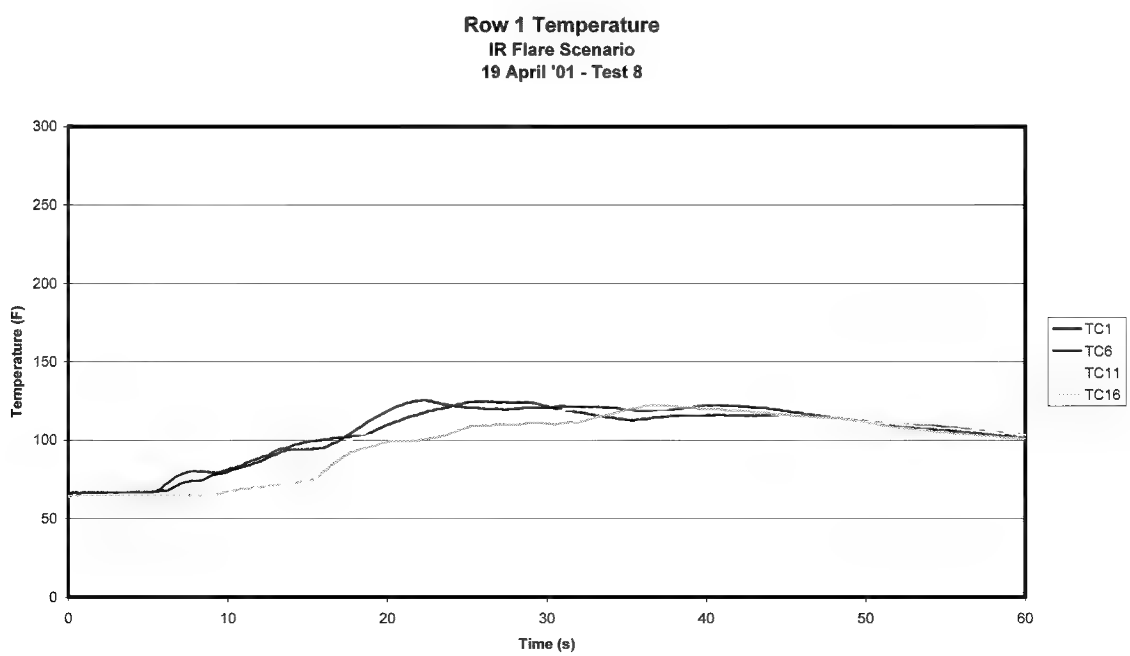


Figure A-59: Test 8 Row 1 Ceiling Temperatures

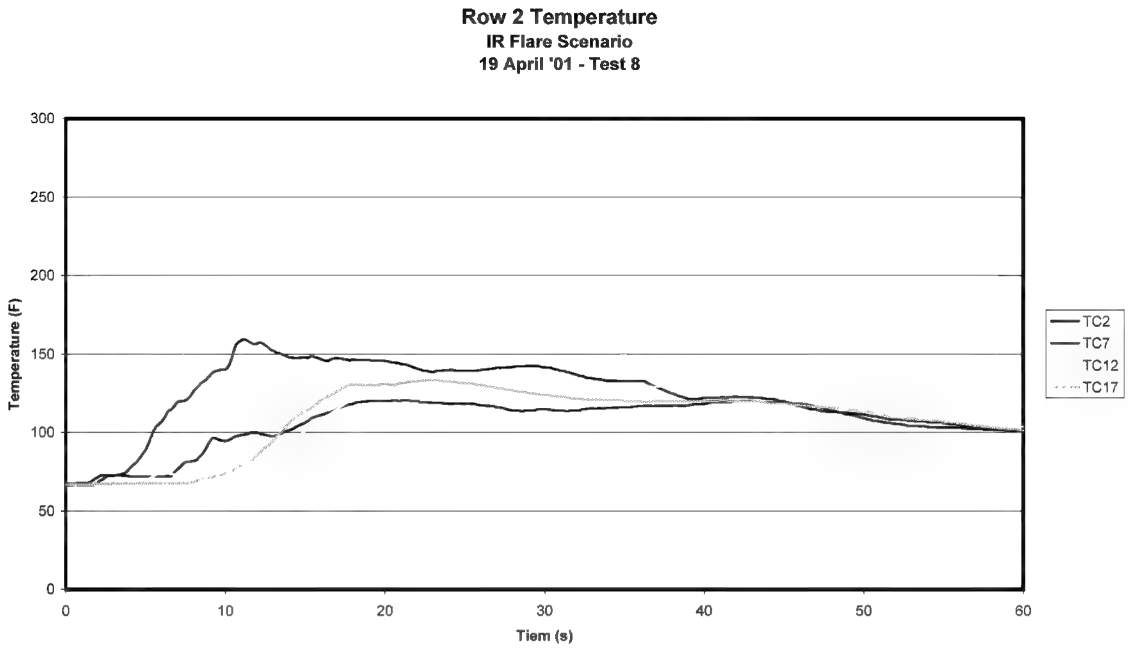


Figure A-60: Test 8 Row 2 Ceiling Temperatures

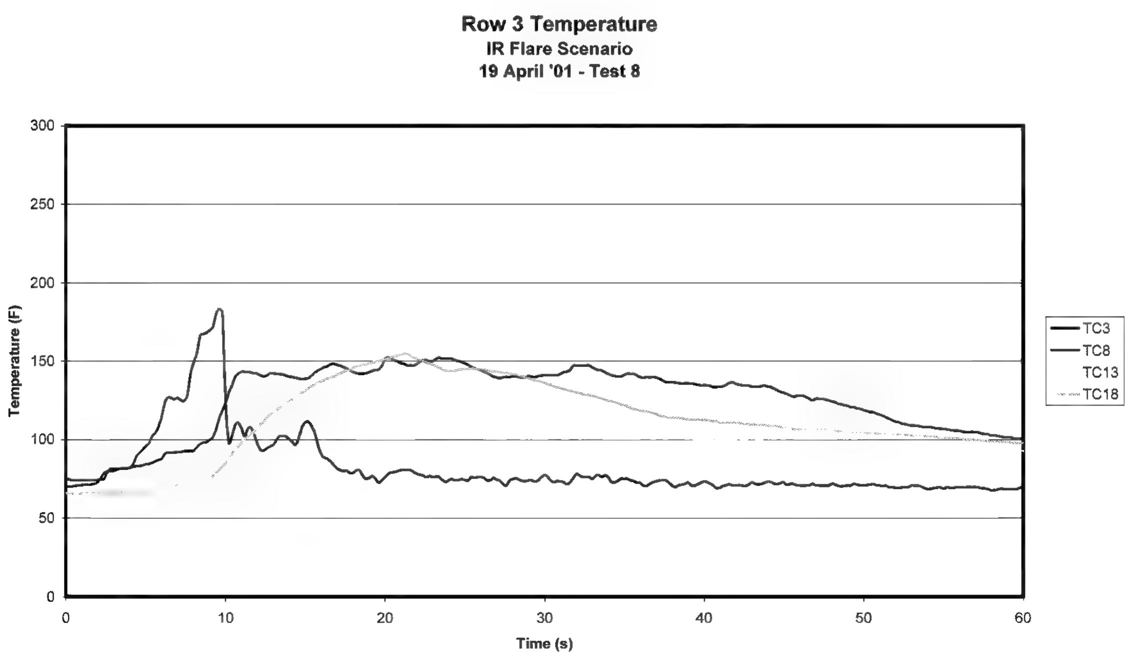


Figure A-61: Test 8 Row 3 Ceiling Temperatures

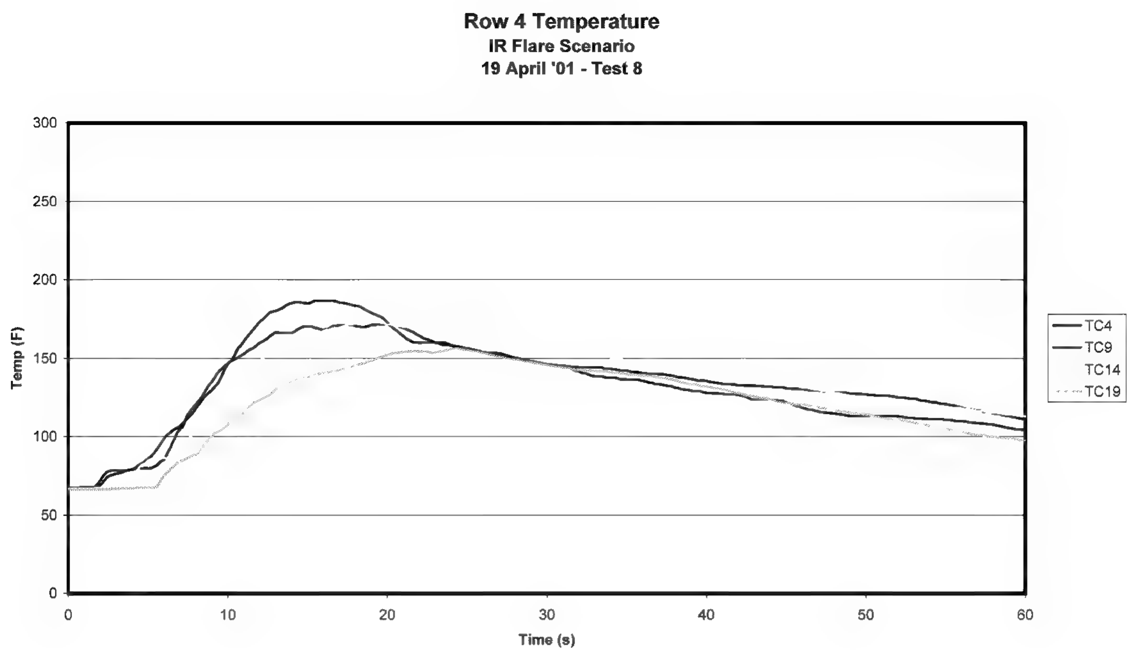


Figure A-62: Test 8 Row 4 Ceiling Temperatures

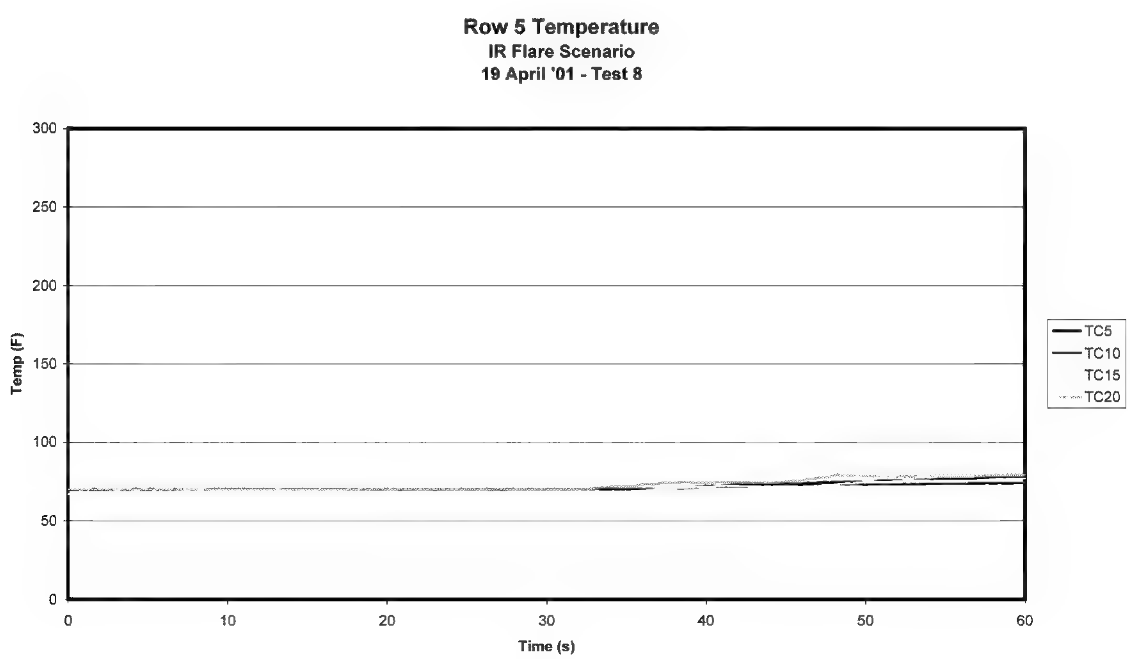


Figure A-63: Test 8 Row 5 Ceiling Temperatures

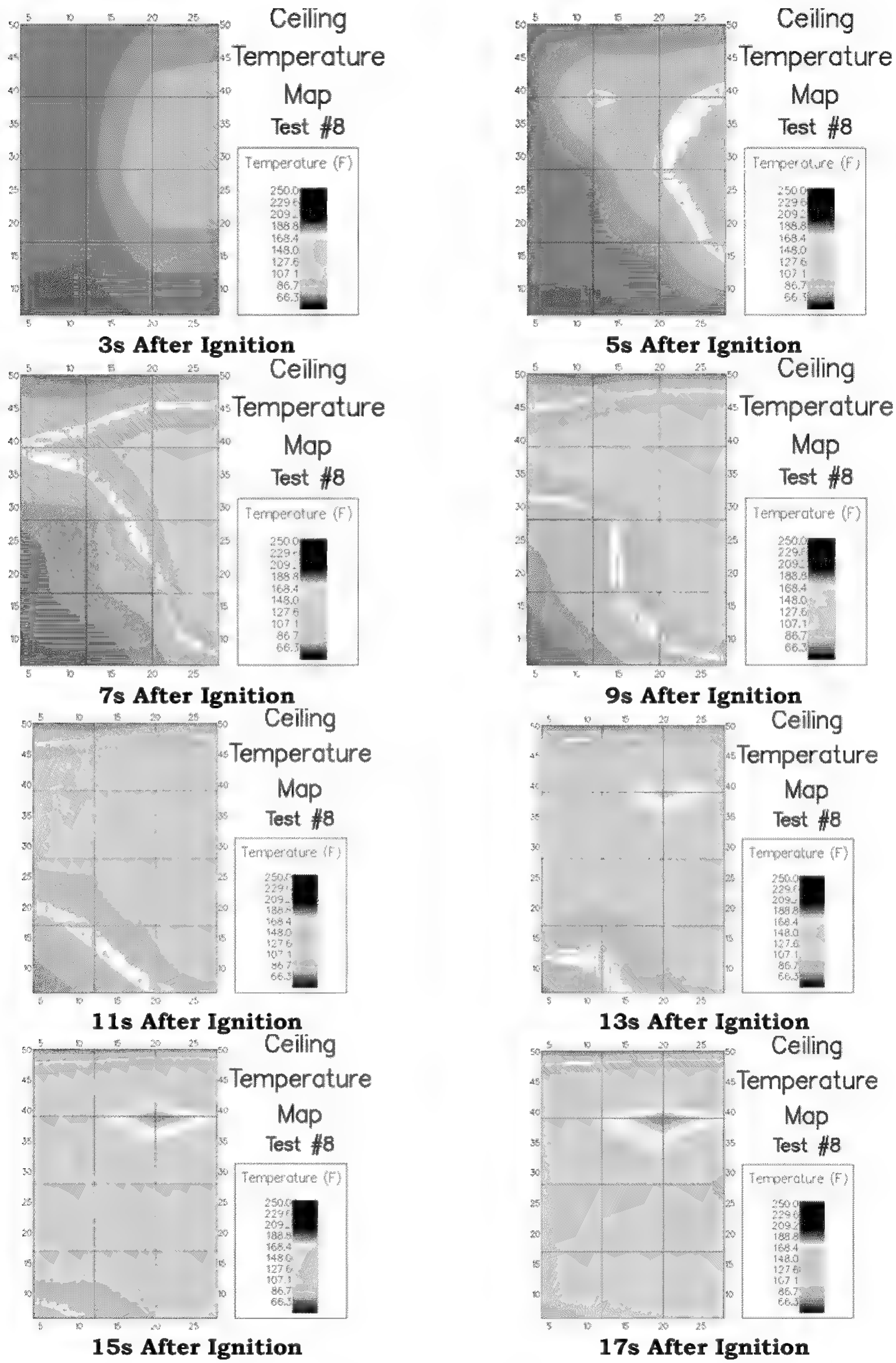


Figure A-64: Test 8 Ceiling Temperatures @ 2 Second Intervals

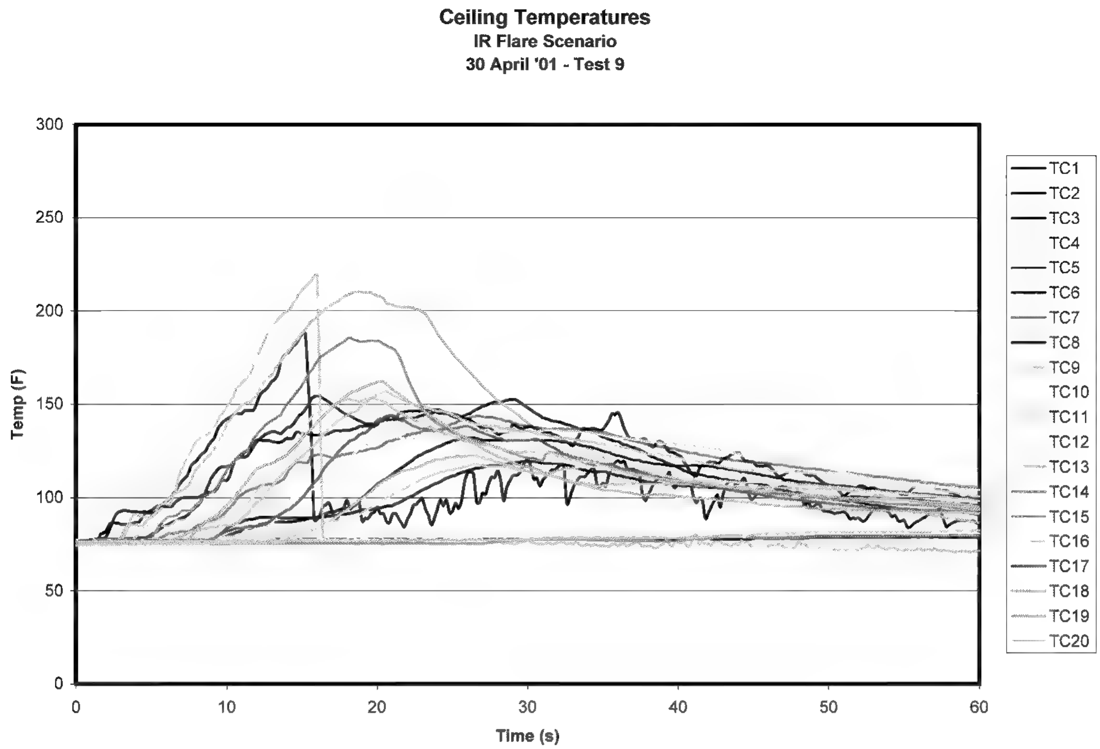


Figure A-65: Test 9 All Ceiling Temperatures

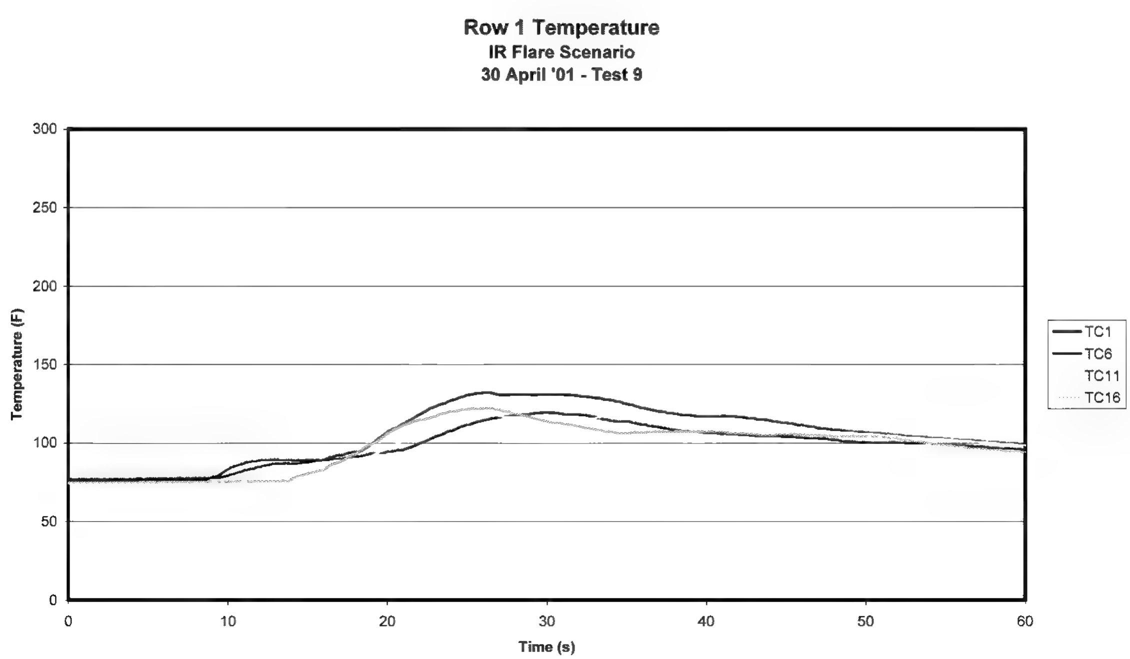


Figure A-66: Test 9 Row 1 Ceiling Temperatures

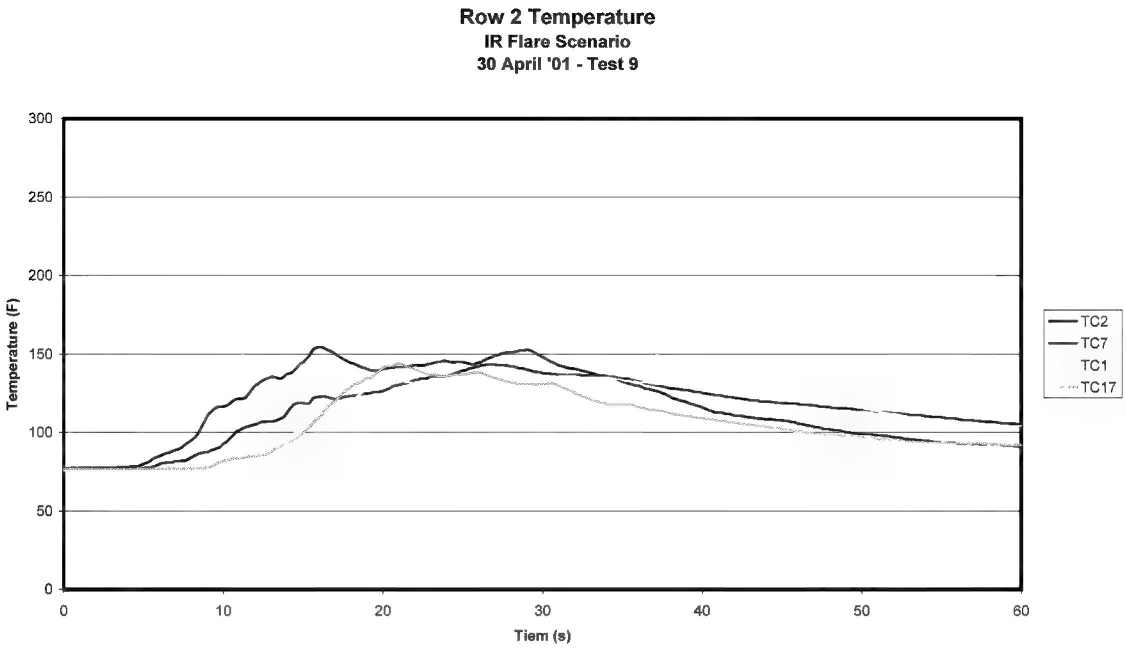


Figure A-67: Test 9 Row 2 Ceiling Temperatures

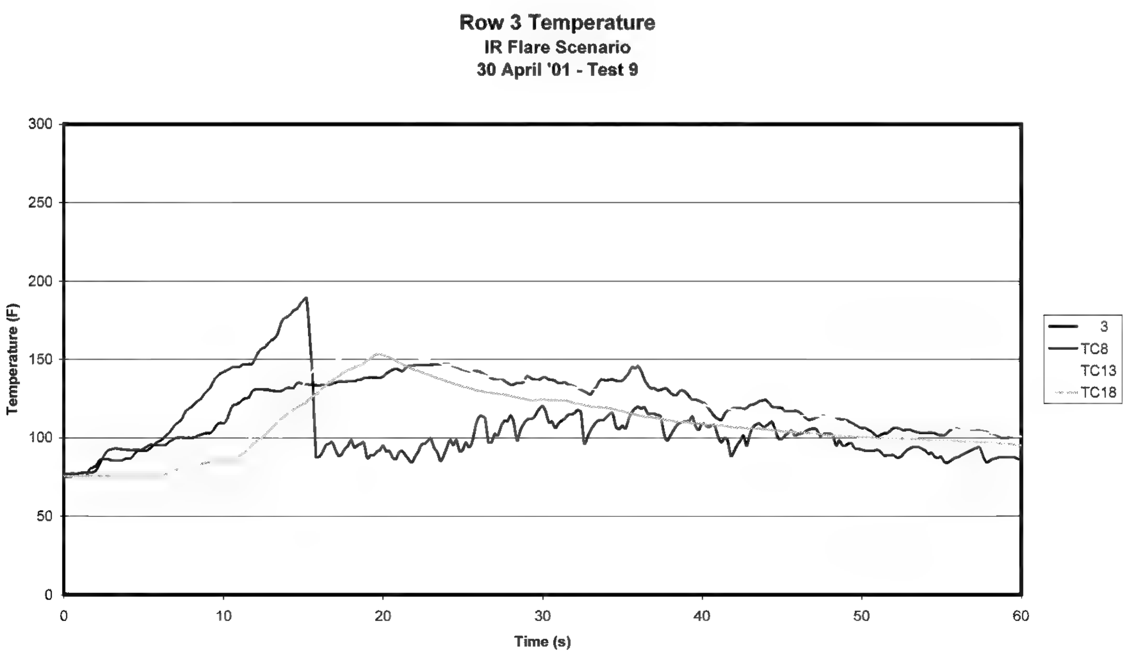


Figure A-68: Test 9 Row 3 Ceiling Temperatures

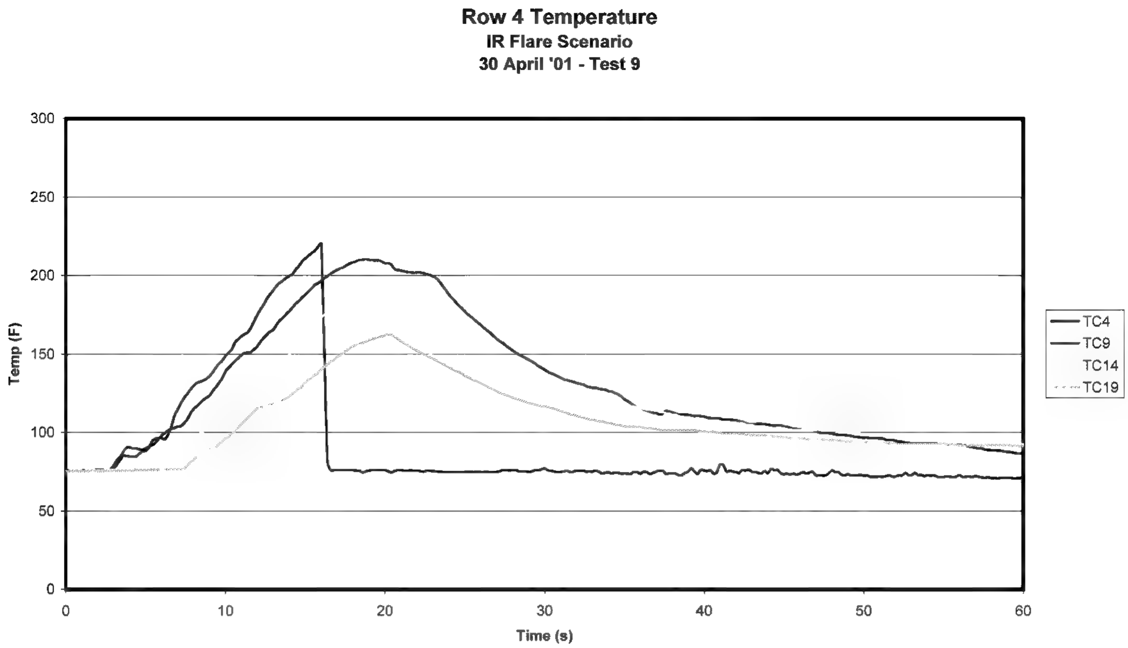


Figure A-69: Test 9 Row 4 Ceiling Temperatures

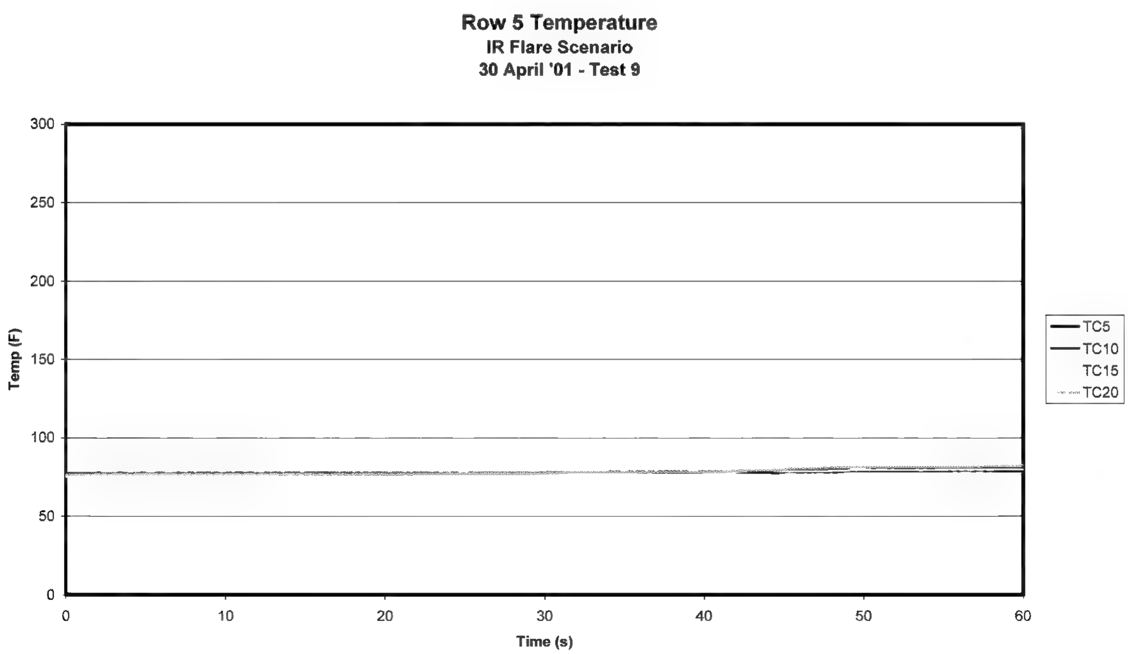


Figure A-70: Test 9 Row 5 Ceiling Temperatures

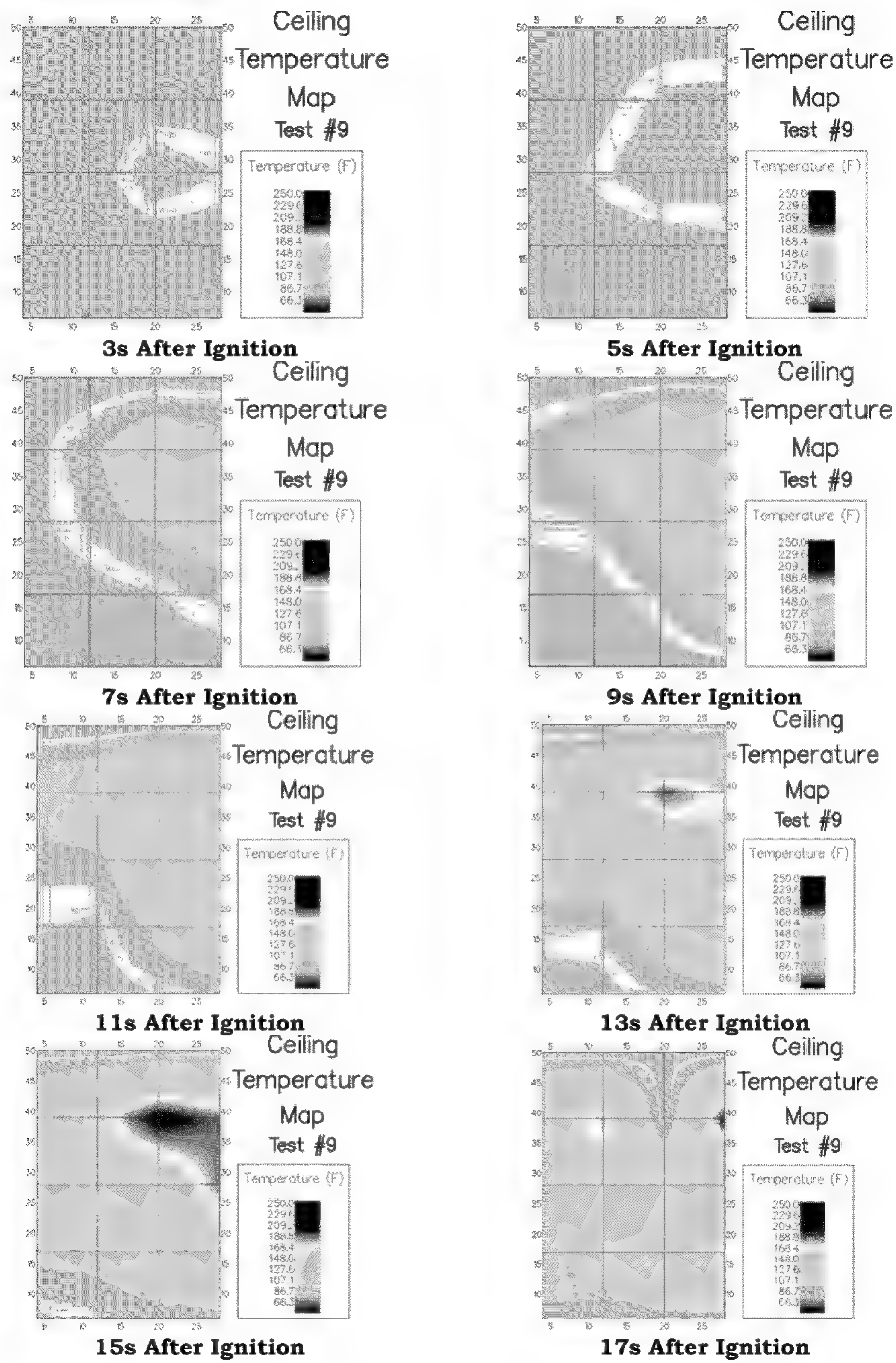


Figure A-71: Test 9 Ceiling Temperatures @ 2 Second Intervals

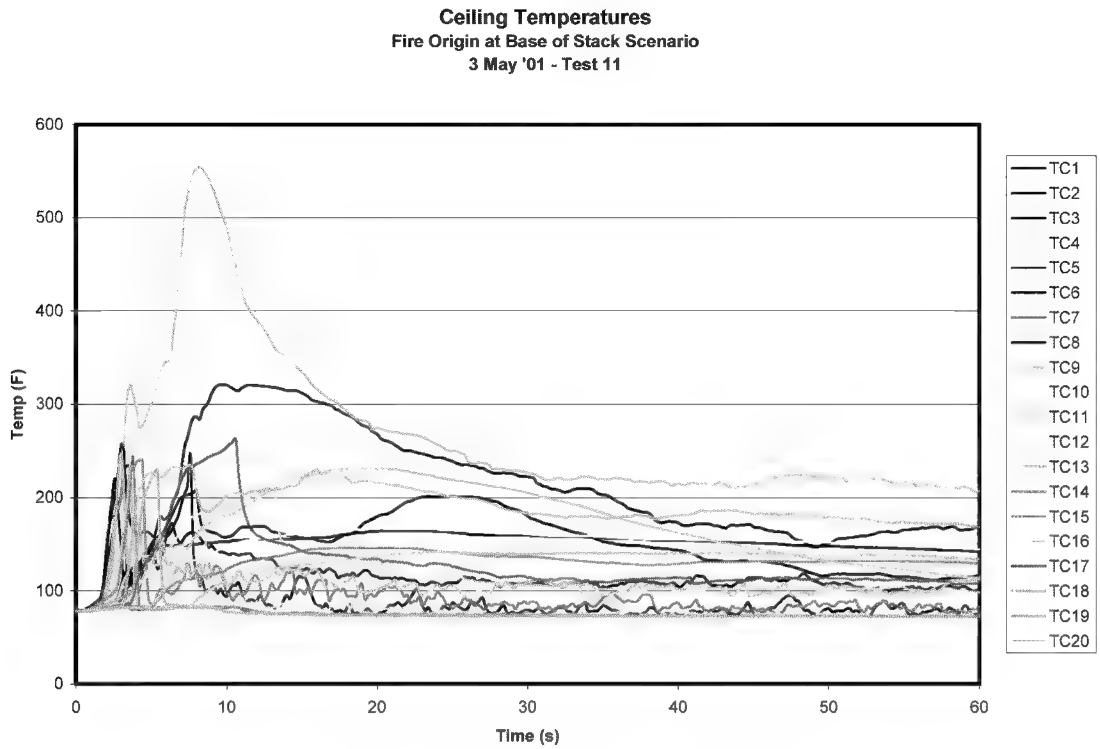


Figure A-72: Test 11 All Ceiling Temperatures

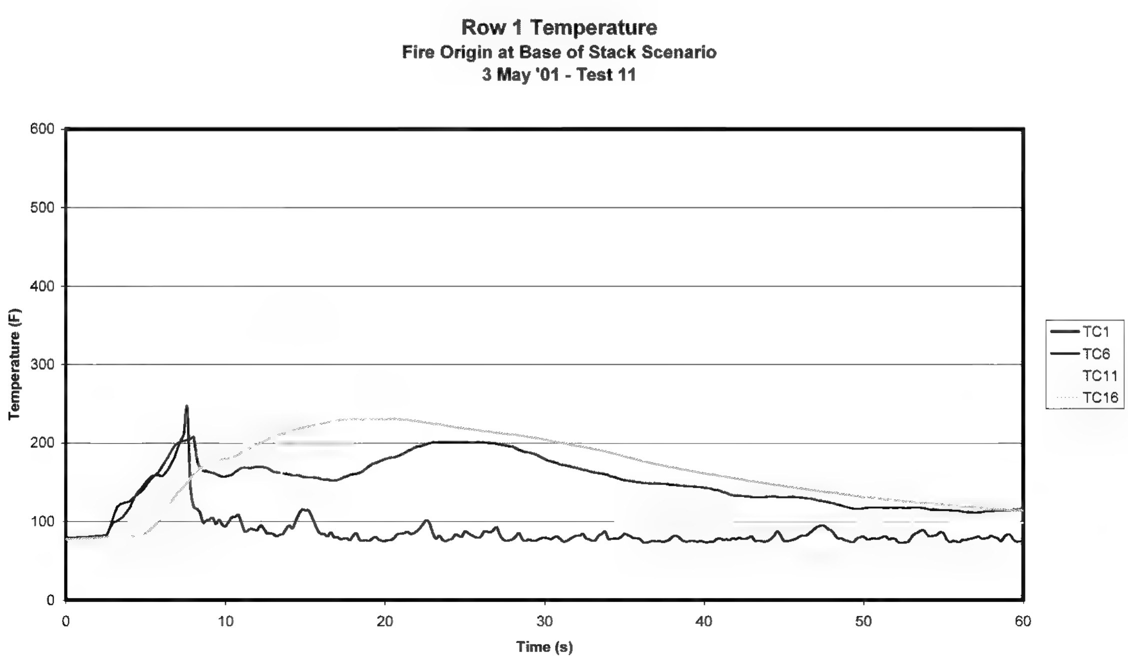


Figure A-73: Test 11 Row 1 Ceiling Temperatures

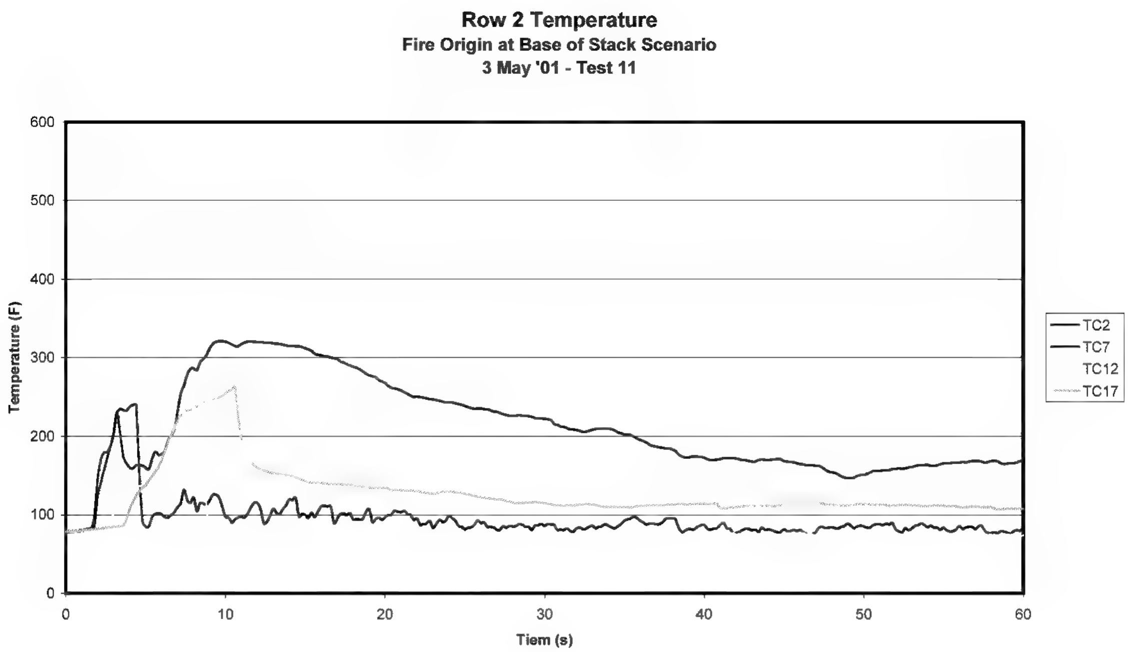


Figure A-74: Test 11 Row 2 Ceiling Temperatures

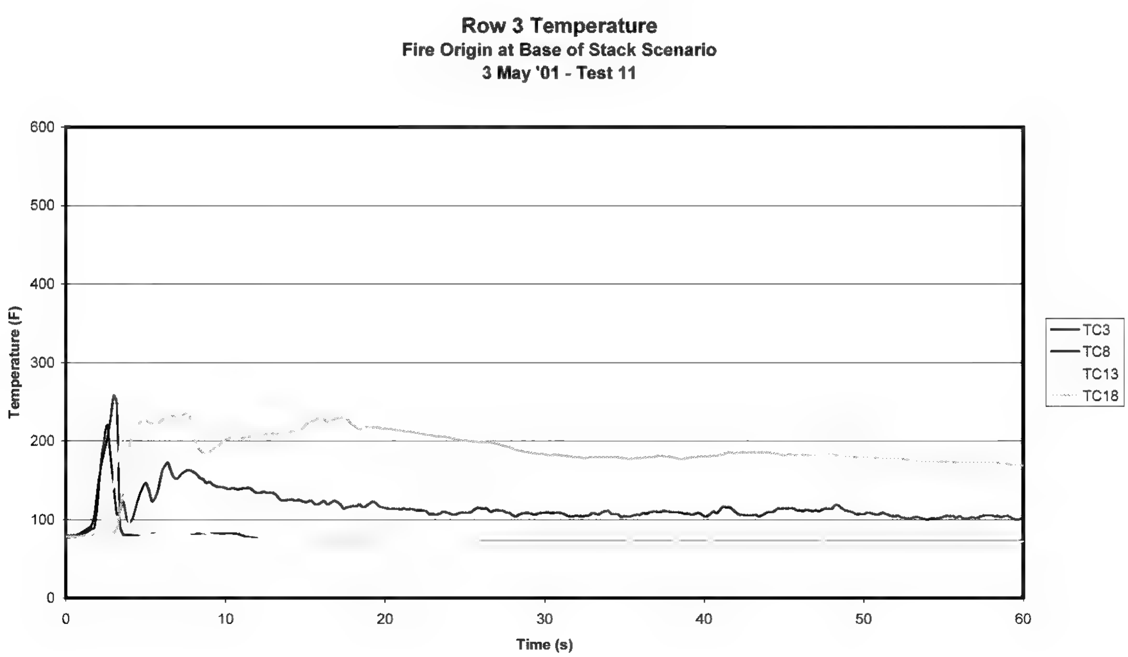


Figure A-75: Test 11 Row 3 Ceiling Temperatures

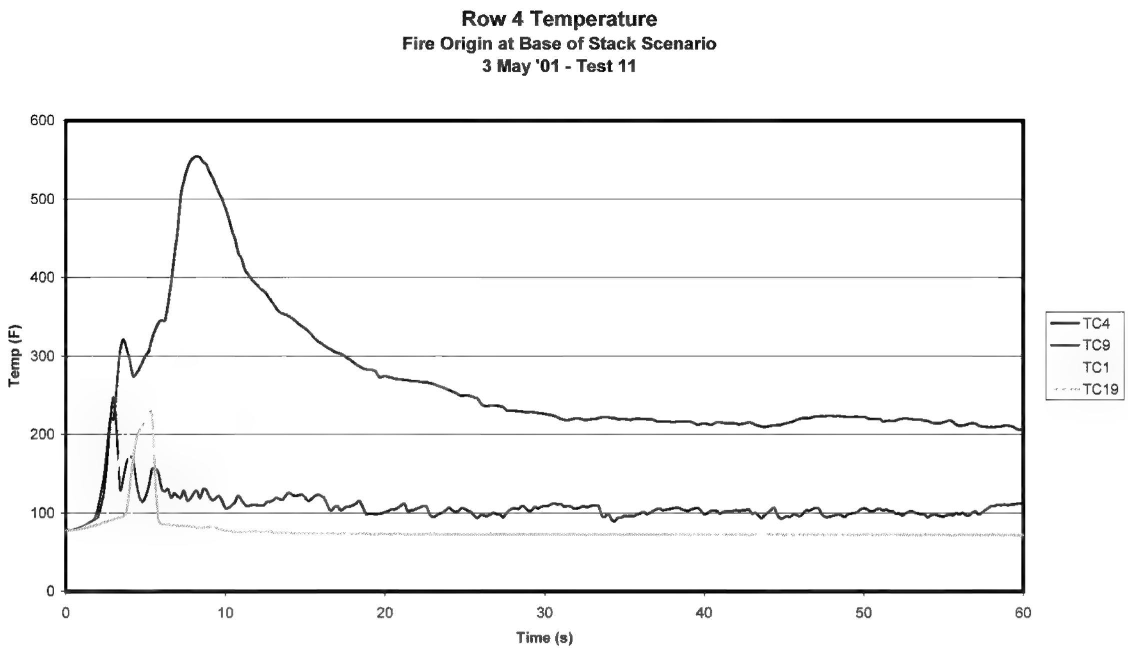


Figure A-76: Test 11 Row 4 Ceiling Temperatures

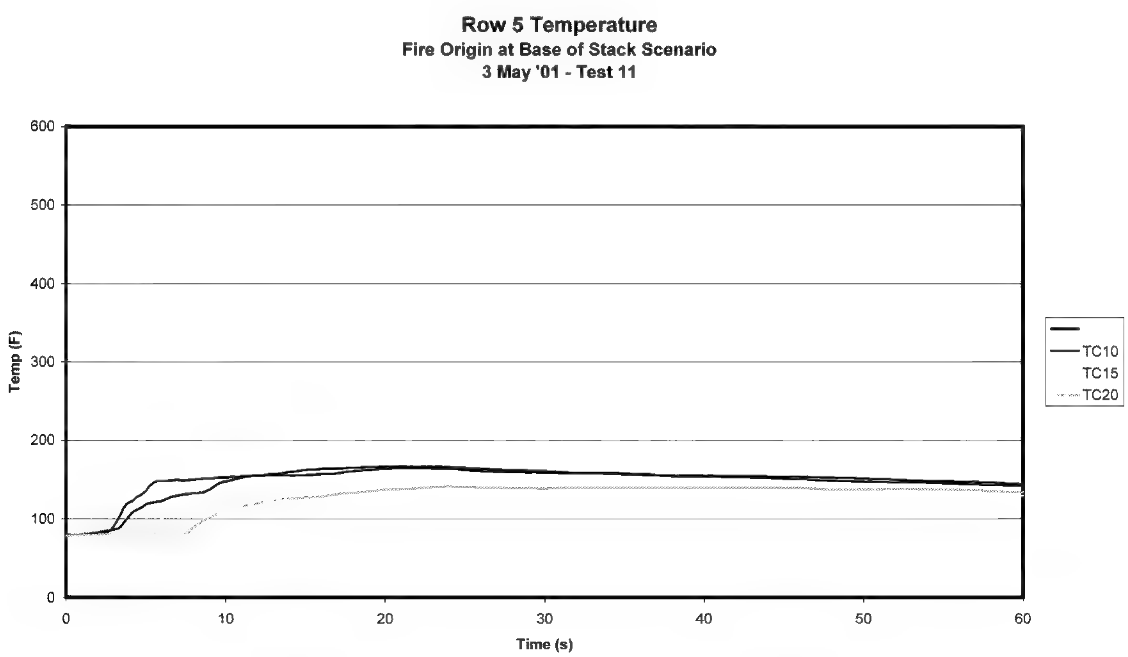


Figure A-77: Test 11 Row 5 Ceiling Temperatures

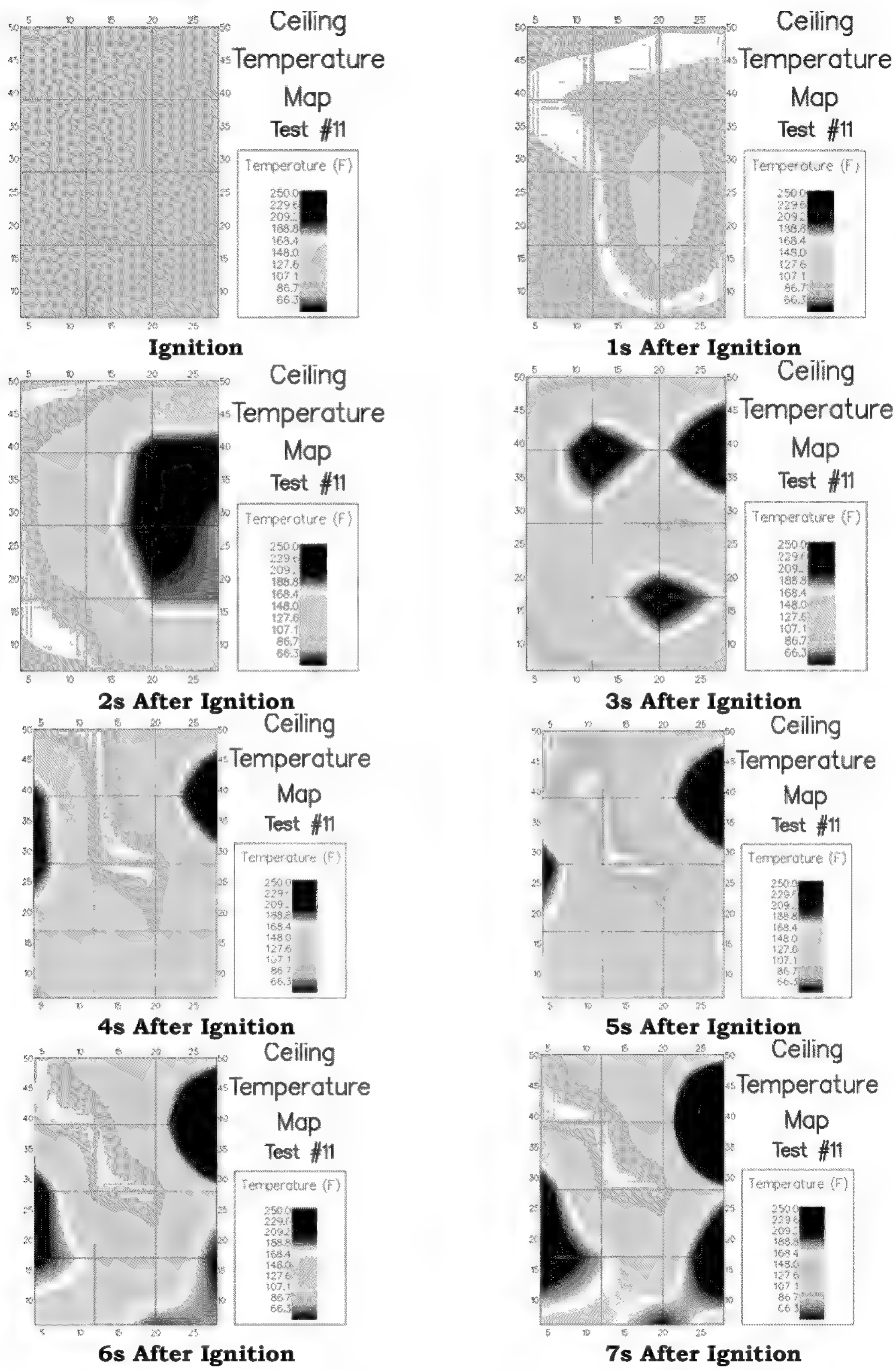


Figure A-78: Test 11 Ceiling Temperatures @ 1 Second Intervals

APPENDIX B

HYDRAULIC DESIGN INFORMATION

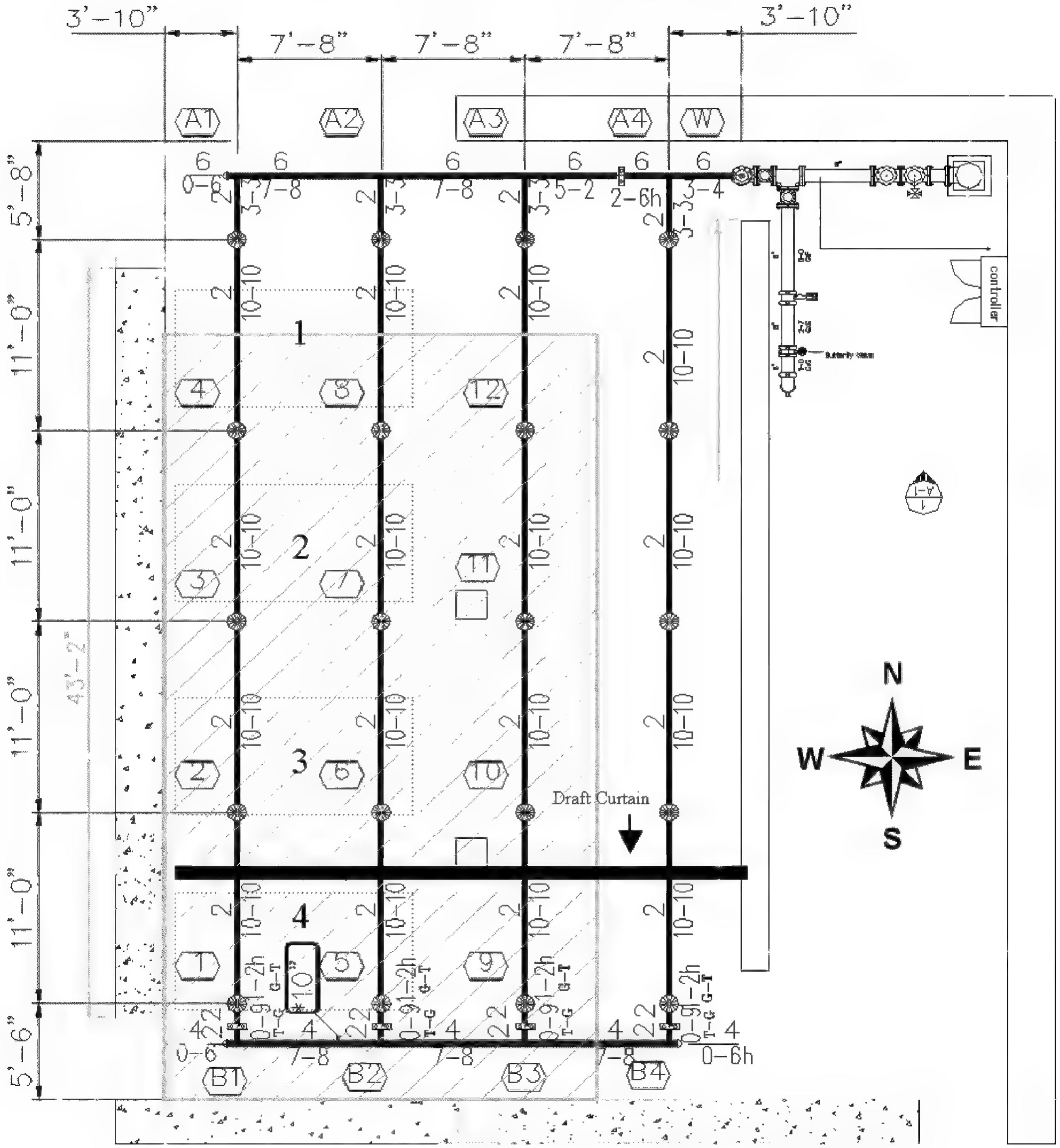


Figure B-1: Sprinkler System Design

HYDRAULIC DESIGN INFORMATION SHEET

Job Name: Air Force Research Laboratory
Location: 104 Research Road
Tyndall AFB, FL. 32403
Drawing Date: 06/25/00 Remote Area Number: 1
Contractor: Telephone:

Designer: John F. Knack
Calculated By:SprinkCALC
CSC Systems & Design
Construction: Occupancy:
Reviewing Authorities:

SYSTEM DESIGN

Code:NFPA 13 Hazard: System Type:WET

Area of Sprinkler Operation	0 sq ft	Sprinkler or Nozzle
Density (gpm/sq ft)	1.000	Make: Model:K25 ULT
Area per Sprinkler	100 sq ft	Orifice:1" K-Factor:25.00
Hose Allowance Inside	0 gpm	Temperature Rating:160
Hose Allowance Outside	0 gpm	

CALCULATION SUMMARY 12 Flowing Outlets
gpm Required: 1421.3 psi Required: -11.3 @ Pump Suction

WATER SUPPLY

Water Flow Test		Pump Data		Tank or Reservoir	
Date of Test		Rated Capacity	1500 gpm	Capacity	0 gal
Static Pressure	0.0 psi	Rated Pressure	75.0 psi	Elevation	0
Residual Pres	0.0 psi	Elevation	0		
At a Flow of	0 gpm	Make: Paterson			
Elevation	0"	Model:		Proof Flow	0 gpm

Location:
Source of Information:

SYSTEM VOLUME 97 Gallons

Notes:

HYDRAULIC CALCULATION DETAILS

```
                                                   HYDRAULIC     FLOW  LOSS
QTY DESCRIPTION                            LENGTH  C     ID       gpm   psi TOTALS

    Hydr Ref W             Required at Hyd Area 1            1421         57.4 psi
  1 6" Grvd 90 Ell                            14' 120  6.065  1421   1.0
  1 Pipe 6" 10x21 CSC Grvd                    15' 120  6.357  1421   0.8
                                                                    ______
                           Total Loss for TO SYSTEM                          1.8 psi
  1 8" Flngd Gate Valve CSC "721U" PIV         4' 120  8.071  1421   0.1
                           Elevation Change 13'0"                    5.6
                                                                    ______
                           Total Loss for THRU RISER                         5.7 psi
                                                                          ______
    Hydr Ref R1            Required at AT BASE OF RISER      1421         64.9 psi
  1 10" Flngd Check Valve CSC "10"            55' 120 10.140  1421   0.3
                                                                          ______
    Hydr Ref R1            Required at Pump Discharge        1421         65.2 psi
  1 75 psi@1500 gpm PUMP
                                                                    ______
                           Total Loss for Pump                             -76.4 psi
                                                                          ______
    Hydr Ref R2            Required at Pump Suction          1421        -11.3 psi
Water Source  0.0 psi static,  0.0 psi residual @    0 gpm 1421 gpm      0.0 psi
                                                                       =======
                           SAFETY PRESSURE                                   0.0 psi
```

Available Pressure of 0.0 psi is NOT SUFFICIENT to meet
Required Pressure of 0 psi by -0 psi

Maximum Water Velocity is 37.7 fps

LEGEND

HYD REF	Hydraulic reference. Refer to accompanying flow diagram.
K FACTOR	Flow factor for open head or path where Flow (gpm) = K x -\/P
SIZE	Nominal size of pipe.
ID	Actual internal diameter of pipe
C	Hazen Williams pipe roughness factor
TYPE	Type or schedule of pipe
# FITS	number of fittings as follows: 90 - 90 deg Ell 45 - 45 deg Ell T - Tee LT - Long Turn 90 Ell SPEC - Fitting other than above or fitting with hydraulic equivalent length specified by manufacturer.
Pt	Total pressure (psi) at fitting
Pf	Friction loss (psi) to fitting where Pf = l x 4.52 x (Q/C)^1.85 / ID^4.87
Pe	Pressure due to change in elevation where Pe = 0.433 x change in elevation
Pv	Velocity pressure (psi) where Pv = 0.001123 x Q^2/ID^4
Pn	Normal pressure (psi) where Pn = Pt - Pv
Pdrop	Pressure loss in pipe rise or drop to an open head.
Phead	Pressure at an open head.
ELEV	elevation from branch tee to open head.
PIPE	pipe length from branch tee to open head.
FITS	fitting equivalent length from branch tee to open head.

NOTES:

- Pressures are balanced to 0.001 gpm. Pressures are listed to 0.01 psi. Addition may vary by 0.01 psi due to accumulation of round off.
- Calculations conform to NFPA 13 edition.
- Velocity Pressures are not considered in these Calculations
- Path #1 is from the most remote head back to the water source.
- Later Paths are from the next most remote head back to previously defined paths

REMOTE AREA #1

	FLOW (GPM)	PIPE	# OF FITS	LENGTH FEET		PRESSURE SUMMARY		BRANCH LINE TO HEAD	
HYD REF	OUTLET	SIZE	90 45	PIPE	VELOCITY	Pt	Pt	Pn	ELEV
		ID	T LT	FITTINGS	LOSS PSI/FT	Pf	Pv	Pdrop	PIPE
K FACTOR	PIPE	C TYPE	OTHER	TOTAL	ELEVATION	Pe	Pn	Phead	FITS

PATH 1 FROM HYDRAULIC REFERENCE 1 TO W (PRIMARY PATH)

HEAD 1	111.8	2"	0 0	2'4"	8.1 fps	20.0		20.0	
1.12 gpm/sq ft		2.067"	1 0	10'0"	0.068	0.8		0.0	
K= 25.00	83.7	120 40	0	12'4"	0"	0.0		20.0	
REF B1		4"	0 0	7'8"	1.9 fps	20.8			
		4.260"	0 0	0"	0.002	0.0			
	83.7	120 10	0	7'8"	0"	0.0			
REF B2	83.7	4"	0 0	7'8"	3.8 fps	20.8			
PATH 3		4.260"	0 0	0"	0.007	0.1			
K= 18.33	167.4	120 10	0	7'8"	0"	0.0			
REF B3	83.8	4"	0 0	7'8"	5.7 fps	20.9			
PATH 5		4.260"	0 0	0"	0.015	0.1			
K= 18.34	251.2	120 10	0	7'8"	0"	0.0			
REF B4		2"	0 0	50'0"	24.3 fps	21.0			
		2.067"	2 0	20'0"	0.516	36.1			
	251.2	120 40	0	70'0"	0"	0.0			
REF A4	1170.1	6"	0 0	3'11"	14.5 fps	57.2			
PATH 2		6.357"	0 0	0"	0.054	0.2			
K=154.78	1421.3	120 10	0	3'11"	0"	0.0			
REF W	1421.3 gpm		PATH 1	K= 187.67		57.4 psi			

PATH 2 FROM HYDRAULIC REFERENCE 1 TO A4

HEAD 1	111.8	2"	0 0	11'0"	2.7 fps	20.0		20.0	
1.12 gpm/sq ft		2.067"	0 0	0"	0.009	0.1		0.0	
K= 25.00	28.1	120 40	0	11'0"	0"	0.0		20.0	
HEAD 2	112.1	2"	0 0	11'0"	13.5 fps	20.1		20.1	
1.12 gpm/sq ft		2.067"	0 0	0"	0.176	1.9		0.0	
K= 25.00	140.2	120 40	0	11'0"	0"	0.0		20.1	
CONTINUED						22.0 psi			

PATH 2 FROM HYDRAULIC REFERENCE 1 TO A4 CONTINUED

HYD REF / K FACTOR	FLOW (GPM) OUTLET / PIPE	PIPE SIZE / ID / C TYPE	# OF FITS 90 45 / T LT / OTHER	LENGTH FEET PIPE / FITTINGS / TOTAL	VELOCITY / LOSS PSI/FT / ELEVATION	PRESSURE SUMMARY Pt / Pf / Pe	Pt / Pv / Pn	BRANCH LINE TO HEAD Pn / Pdrop / Phead	ELEV / PIPE / FITS
HEAD 3	117.3	2"	0 0	11'0"	24.9 fps	22.0		22.0	
1.17 gpm/sq ft		2.067"	0 0	0"	0.541	5.9		0.0	
K= 25.00	257.6	120 40	0	11'0"	0"	0.0		22.0	
HEAD 4	132.2	2"	0 0	14'8"	37.6 fps	28.0		28.0	
1.32 gpm/sq ft		2.067"	1 0	10'0"	1.164	28.7		0.0	
K= 25.00	389.8	120 40	0	24'8"	0"	0.0		28.0	
REF A1		6"	0 0	7'8"	4.0 fps	56.7			
		6.357"	0 0	0"	0.005	0.0			
	389.8	120 10	0	7'8"	0"	0.0			
REF A2	389.9	6"	0 0	7'8"	8.0 fps	56.7			
PATH 4		6.357"	0 0	0"	0.018	0.1			
K= 51.77	779.7	120 10	0	7'8"	0"	0.0			
REF A3	390.4	6"	0 0	7'8"	11.9 fps	56.9			
PATH 6		6.357"	0 0	0"	0.037	0.3			
K= 51.77	1170.1	120 10	0	7'8"	0"	0.0			
REF A4	1170.1 gpm		PATH 2	K=	154.78	57.2 psi			

PATH 3 FROM HYDRAULIC REFERENCE 5 TO B2

HYD REF / K FACTOR	FLOW (GPM) OUTLET / PIPE	PIPE SIZE / ID / C TYPE	# OF FITS 90 45 / T LT / OTHER	LENGTH FEET PIPE / FITTINGS / TOTAL	VELOCITY / LOSS PSI/FT / ELEVATION	PRESSURE SUMMARY Pt / Pf / Pe	Pt / Pv / Pn	BRANCH LINE TO HEAD Pn / Pdrop / Phead	ELEV / PIPE / FITS
HEAD 5	111.8	2"	0 0	2'4"	8.1 fps	20.0		20.0	
1.12 gpm/sq ft		2.067"	1 0	10'0"	0.068	0.8		0.0	
K= 25.00	83.7	120 40	0	12'4"	0"	0.0		20.0	
REF B2	83.7 gpm		PATH 3	K=	18.33	20.8 psi			

PATH 4 FROM HYDRAULIC REFERENCE 5 TO A2

HYD REF / K FACTOR	FLOW (GPM) OUTLET / PIPE	PIPE SIZE / ID / C TYPE	# OF FITS 90 45 / T LT / OTHER	LENGTH FEET PIPE / FITTINGS / TOTAL	VELOCITY / LOSS PSI/FT / ELEVATION	PRESSURE SUMMARY Pt / Pf / Pe	Pt / Pv / Pn	BRANCH LINE TO HEAD Pn / Pdrop / Phead	ELEV / PIPE / FITS
HEAD 5	111.8	2"	0 0	11'0"	2.7 fps	20.0		20.0	
1.12 gpm/sq ft		2.067"	0 0	0"	0.009	0.1		0.0	
K= 25.00	28.1	120 40	0	11'0"	0"	0.0		20.0	
CONTINUED						20.1 psi			

HYD REF / K FACTOR	FLOW (GPM) OUTLET / PIPE	PIPE SIZE / ID / C TYPE	# OF FITS 90 45 / T LT / OTHER	LENGTH FEET PIPE / FITTINGS / TOTAL	VELOCITY / LOSS PSI/FT / ELEVATION	PRESSURE SUMMARY Pt / Pf / Pe	Pt / Pv / Pn	BRANCH LINE TO HEAD Pn / Pdrop / Phead	ELEV / PIPE / FITS
PATH 4 FROM HYDRAULIC REFERENCE 5 TO A2 CONTINUED									
HEAD 6	112.1	2"	0 0	11'0"	13.5 fps	20.1		20.1	
1.12 gpm/sq ft		2.067"	0 0	0"	0.176	1.9		0.0	
K= 25.00	140.3	120 40	0	11'0"	0"	0.0		20.1	
HEAD 7	117.4	2"	0 0	11'0"	24.9 fps	22.0		22.0	
1.17 gpm/sq ft		2.067"	0 0	0"	0.541	6.0		0.0	
K= 25.00	257.6	120 40	0	11'0"	0"	0.0		22.0	
HEAD 8	132.3	2"	0 0	14'8"	37.6 fps	28.0		28.0	
1.32 gpm/sq ft		2.067"	1 0	10'0"	1.165	28.7		0.0	
K= 25.00	389.9	120 40	0	24'8"	0"	0.0		28.0	
REF A2	389.9 gpm		PATH 4	K= 51.77		56.7 psi			
PATH 5 FROM HYDRAULIC REFERENCE 9 TO B3									
HEAD 9	112.0	2"	0 0	2'4"	8.1 fps	20.1		20.1	
1.12 gpm/sq ft		2.067"	1 0	10'0"	0.068	0.8		0.0	
K= 25.00	83.8	120 40	0	12'4"	0"	0.0		20.1	
REF B3	83.8 gpm		PATH 5	K= 18.34		20.9 psi			
PATH 6 FROM HYDRAULIC REFERENCE 9 TO A3									
HEAD 9	112.0	2"	0 0	11'0"	2.7 fps	20.1		20.1	
1.12 gpm/sq ft		2.067"	0 0	0"	0.009	0.1		0.0	
K= 25.00	28.2	120 40	0	11'0"	0"	0.0		20.1	
HEAD 10	112.3	2"	0 0	11'0"	13.6 fps	20.2		20.2	
1.12 gpm/sq ft		2.067"	0 0	0"	0.176	1.9		0.0	
K= 25.00	140.4	120 40	0	11'0"	0"	0.0		20.2	
HEAD 11	117.5	2"	0 0	11'0"	24.9 fps	22.1		22.1	
1.18 gpm/sq ft		2.067"	0 0	0"	0.542	6.0		0.0	
K= 25.00	258.0	120 40	0	11'0"	0"	0.0		22.1	
CONTINUED						28.1 psi			

	FLOW (GPM)	PIPE	# OF FITS	LENGTH FEET		PRESSURE SUMMARY		BRANCH LINE TO HEAD	
HYD REF	OUTLET	SIZE	90 45	PIPE	VELOCITY	Pt	Pt	Pn	ELEV
		ID	T LT	FITTINGS	LOSS PSI/FT	Pf	Pv	Pdrop	PIPE
K FACTOR	PIPE	C TYPE	OTHER	TOTAL	ELEVATION	Pe	Pn	Phead	FITS

PATH 6 FROM HYDRAULIC REFERENCE 9 TO A3 CONTINUED

HEAD 12	132.5	2"	0 0	14'8"	37.7 fps	28.1		28.1	
1.32 gpm/sq ft		2.067"	1 0	10'0"	1.168	28.8		0.0	
K= 25.00	390.4	120 40	0	24'8"	0"	0.0		28.1	

REF A3 390.4 gpm PATH 6 K= 51.77 56.9 psi